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For: **METHOD AND APPARATUS FOR DIGITAL WATERMARKING**

Enclosed are:

☒ **Thirty (30)** sheets of drawing.

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Date: **August 31, 1999**

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Edward W. Greason

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SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Hiroshi Ogawa, a citizen of Japan residing at Yokohama-shi, Kanagawa-ken, Japan, Takao Nakamura, a citizen of Japan residing at Yokohama-shi, Kanagawa-ken, Japan, Atsuki Tomioka, a citizen of Japan residing at Yokohama-shi, Kanagawa-ken, Japan and Youichi Takashima, a citizen of Japan residing at Yokohama-shi, Kanagawa-ken, Japan have invented certain new and useful improvements in

METHOD AND APPARATUS FOR DIGITAL WATERMARKING

of which the following is a specification:-

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TITLE OF THE INVENTION

METHOD AND APPARATUS FOR DIGITAL
WATERMARKING

5 BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to
a digital watermarking technique. More particularly,
the present invention relates to a digital
10 watermarking technique for embedding or reading
digital watermark data in digital data contents
which represent an image or a sound. In addition,
the present invention relates to a technique for
statistical processing of read watermark data in a
15 system using the digital watermarking technique.

It is easy to replicate or tamper
fraudulently with multimedia production, and the
easeiness hinders an data content provider from
sending data. In addition, some users may not use
20 the data originated from the provider validly.
Therefore, copyright protection is strongly needed
for the multimedia production. The digital
watermarking technique is effective in realizing the
copyright protection. According to the digital
25 watermarking technique, sub-data is embedded in data
contents without being noticed by a user by
utilizing redundancy of data such as of an image and
a sound. The digital watermarking technique is used
for protecting a multimedia copyright by embedding
30 copyright information, a user ID and the like as the
sub-data in secret, since it is difficult to
separate the sub-data from the data contents.

2. Description of the Related Art

Conventionally, the following digital
35 watermarking techniques are proposed.

According to a technique proposed in
Japanese patent application No.9-57516, "Image

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processing method and the apparatus," an image is subdivided into blocks larger than a 8×8 block size which is used for common non reversible compression. Then, the size of the frequency coefficient which is obtained by discrete Fourier transform of the block is changed, the frequency coefficient being represented by a polar coordinate system and the size being a distance from the origin point of the polar coordinate system. As a result, sub-data can be read correctly even when the non-reversible compression is performed. In addition, the frequency coefficient is normalized within a range of predetermined values, is embedded, and read. In addition, weaker image processing is carried out on a complicated region as compared to a flat region. As a result, degradation of image quality which may be caused by embedding the sub-data can be suppressed and a tolerance to contrast changing is obtained. Further, as the value of the frequency coefficient to be changed becomes larger, the modification amount of the frequency coefficient becomes larger (the smaller the value is, the smaller the modification amount is) so as to suppress the deterioration of image quality more effectively. In addition, when subdividing an image into blocks, an image area which is smaller than one block is treated as one block by using an average pixel value and/or using a form symmetric with respect to a line repeatedly to compensate for the lacking image area. Moreover, the sub-data is constituted from the whole image after weighting data of each block. As a result, the sub-data is read correctly even when the image is partly edited and/or the image with many flat parts is non-reversibly compressed.

In addition, according to a technique proposed in Japanese patent application No.9-164466,

5 Further, frequency conversion is carried out with a
block size larger than a block size used for data
compression, and, then data embedding is carried out.
Moreover, an original image is used when data is
read. As a result, tolerance to data compression is
10 obtained.

Other conventional techniques are proposed in Japanese patent applications No.8-305370, No.8-338769, No.9-9812, No.9-14388, No.9-109924, No.9-197003, No.9-218467 and No.10-33239. The digital watermark method is also called data hiding, finger printing steganography, image/sound deep encryption and the like.

Elements for determining performance of the digital watermarking technique are as follows:

- (1) quality of data contents in which the digital watermark is embedded;
- (2) durability of the digital watermark which is embedded in the data contents when the data contents are manipulated;
- (3) safety against intentional erasing of and tampering with digital watermark data, and
- (4) reliability of the digital watermark data which is read from the data contents.

The digital watermarking technique is broadly divided into two methods. One method of gives meaning to a data value by quantizing. For 35 example, by dividing a data value by a quantization value and dividing the result by 2, a bit data can be represented by the remainder. Another method

embeds digital watermark data by using a spread spectrum method.

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The above-mentioned examples are based on the former method. In terms of the method, there is a problem with respect to the above element (1) in that the digital watermark data embedded in the data contents may be perceived, or commercial value of the data contents may be lost by embedding the digital watermark data. With respect to the above element (2), the digital watermark data which is embedded in the data contents may be dissipated even when a general user uses the data contents in a normal way. Particularly, it is a difficult problem to achieve both elements (1) and (2) with enough performance in practical use.

In addition, there is a method of embedding the digital watermark data repeatedly in order to give durability to the digital watermark data against manipulation of the data contents. Specifically, according to the method, digital watermark data which is embedded repeatedly (which is called a watermark sequence hereinafter) is read from data contents, and, then, the digital watermark data is reconstituted by performing statistical processing. The watermark sequence has durability against deterioration and noise to some extent. However, if the data contents are encoded by high compression rates, it may become difficult to read the watermark sequence from the data contents. Therefore, it may become impossible to reconstitute the digital watermark data.

In addition, as for a digital watermarking system, accuracy for determining the presence or absence of embedded data is important. In addition, reliability of embedded data is important. The digital watermarking system generally has a mechanism for reconstituting correct digital

5 However, under present circumstances, it is impossible for the system to evaluate validity of reconstituted digital watermark data quantitatively. Therefore, the system does not have enough reliability.

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receiving the digital data contents and
the digital watermark data;

dividing the digital data contents into
block data;

5 obtaining a frequency coefficient of the
block data;

obtaining a complexity of the block data;

obtaining an amount of transformation of
the frequency coefficient from the complexity and
10 the digital watermark data by using a quantization
width;

embedding the digital watermark data in
said digital data contents by transforming the
frequency coefficient by the amount; and

15 generating watermarked digital data
contents.

The first object of the present invention
is also achieved by a method including the steps of:

receiving the digital data contents and
20 the digital watermark data;

dividing the digital data contents into
block data;

obtaining a frequency coefficient of the
block data;

25 obtaining an amount of transformation of
the frequency coefficient from the digital watermark
data by using a quantization width corresponding to
the frequency coefficient, the quantization width
being obtained beforehand according to a

30 manipulation method of the digital data contents;

embedding the digital watermark data in
said digital data contents by transforming the
frequency coefficient by the amount; and

generating watermarked digital data
35 contents.

According to the above-mentioned
inventions, the amount of transformation of

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frequency coefficients is changed and/or the amount of transformation is increased or decreased according to the complexity of the digital data contents. Therefore, the quality of the watermarked digital data contents can be improved and the durability of digital watermark data against a manipulation of the watermarked digital data contents can be improved.

The second object of the present invention is achieved by a method for reading digital watermark data embedded in digital data contents, the method including the steps of:

receiving the digital data contents;
reading a bit sequence from the digital data contents;
calculating a probability of reading a bit '1' or a bit '0' in the bit sequence by using a test method on the basis of binary distribution;
determining the presence or absence of digital watermark data according to the probability; and
reconstituting and generating the digital watermark data from the bit sequence.

According to the above-mentioned invention, probabilities of the following cases can be evaluated quantitatively. The cases are that digital data contents which do not contain digital watermark data are wrongly judged as containing digital watermark data, and incorrect digital watermark data is read from watermarked digital data contents. In addition, the probability can be suppressed within a constant value.

The third object of the present invention is achieved by a method for reading digital watermark data from digital data contents in which each bit of digital watermark data is embedded a plurality of times, the method including the steps

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of:

receiving digital data contents;
reading a digital watermark sequence from
the digital data contents;

5 performing soft decision in code theory by
assigning weights to the digital watermark sequence
with a weighting function;

reconstituting the digital watermark data
from the digital watermark sequence.

10 According to the above-mentioned invention,
the digital watermark data sequence is separated
from the noise so that error bits which are included
in the digital watermark data sequence can be
reduced, thereby the digital watermark data reading
15 success rate being improved in comparison with the
conventional method. In addition, since weights are
assigned to the digital watermark data sequence, the
present invention is especially effective when the
repeating number of watermark embedding is small.

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BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of
the present invention will become more apparent from
the following detailed description when read in
25 conjunction with the accompanying drawings, in
which:

Fig.1 is a block diagram of a digital
watermarking system of the present invention;

Fig.2 is a general flowchart showing a
30 digital watermark embedding process according to a
conventional technique;

Fig.3 is a detailed flowchart showing a
principal part of the digital watermark embedding
process according to the conventional technique;

35 Fig.4 is a conceptual diagram of the
digital watermark embedding process according to the
conventional technique;

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Fig.5 is a general flowchart showing a digital watermark reading process according to the conventional technique;

Fig.6 is a detailed flowchart showing a principal part of the digital watermark reading process according to the conventional technique;

Fig.7 is a block diagram showing receiving data and generating data of a digital watermark embedding apparatus of the present invention;

Fig.8 is a block diagram showing receiving data and generating data of a digital watermark reading apparatus of the present invention;

Fig.9 is a general flowchart showing a digital watermark embedding process according to a first embodiment of the present invention;

Fig.10 is a detailed flowchart showing a principal part of the digital watermark embedding process according to the first embodiment of the present invention;

Figs.11A and 11B are conceptual diagrams of the digital watermark embedding process according to the first embodiment of the present invention;

Fig.12 is a flowchart of a process for calculating a data complexity according to a second embodiment of the present invention;

Fig.13 is a flowchart showing a process for obtaining a watermark weight ratio data according to the present invention;

Fig.14 is a detailed flowchart showing a principal part of the digital watermark embedding process according to a third embodiment of the present invention;

Fig.15 is a detailed flowchart showing a principal part of the digital watermark reading process according to a fourth embodiment of the present invention;

Fig.16 is a flowchart showing a process of

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calculating a watermark strength matrix according to a fifth embodiment of the present invention;

Fig.17 is a block diagram of a computer;

Fig.18 is a block diagram of an integrated
5 circuit;

Fig.19 is a block diagram of a digital watermarking system of the present invention;

Fig.20 is a block diagram of a digital watermark reading apparatus shown in Fig.19;

Fig.21 is a diagram for explaining
10 judgment on digital watermark data;

Fig.22 is a conceptual diagram of reconstituting digital watermark data;

Fig.23 is a flowchart of a digital
15 watermark reading process according to a seventh embodiment of the present invention;

Fig.24 is a block diagram of a digital watermarking system according to an eighth embodiment of the present invention;

Fig.25 is a flowchart of a digital
20 watermark reading process according to a tenth embodiment of the present invention;

Fig.26 is a flowchart of a digital watermark reading process according to a tenth
25 embodiment of the present invention when reading digital watermark data sequence which is embedded after being modulated by a pseudo-random sequence;

Fig.27 is a diagram showing the result of
30 reading a digital watermark data sequence without modulation;

Fig.28 is a diagram showing the result of reading a modulated digital watermark data sequence;

Fig.29 is a diagram showing a digital watermark reading process according to a
35 conventional technique;

Fig.30 is a graph showing how MPEG-1 coding changes '1' data bit, specifically the graph

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shows occurrence frequency with respect to change amount of a DCT coefficient value by 1.5-Mbps MPEG - 1 coding;

Fig.31 is a flowchart showing a principle of a thirteenth embodiment of the present invention corresponding to a third object;

Fig.32 is a block diagram of a digital watermark reading apparatus according to the thirteenth embodiment of the present invention;

Fig.33 is a general flowchart showing a digital watermark reading process according to the thirteenth embodiment of the present invention;

Fig.34 is a diagram showing the result of comparison of a digital watermark data reading success rate between a conventional reading method and the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before explaining embodiments of the present invention, definition of some words will be given. "Digital watermark data sequence" represents a data sequence read from the digital data contents before being reconstituted. "Digital watermark data" represents significant data for system operation, which data needs to be embedded in the digital data contents, or, data obtained by reconstituting the digital watermark sequence. "Reliability α of digital watermark" is an index representing validity of read digital watermark data. That is, it represents a probability that the read digital watermark data matches with the actual embedded digital watermark data. Conversely, a probability of reading digital watermark data from an image without digital watermark data or reading erroneous digital watermark data can be represented as $2(1-\alpha)$. Similarly, "embedded sequence" represents data to be actually embedded. The embedded sequence includes

sequence of embedded data which is modulated, extended or repeated. In addition, "read" may be replaced with "extract" in some cases.

Fig.1 shows a digital watermarking system of the present invention. In the system shown in Fig.1, digital watermark data 101 is embedded in digital data contents 103 by a digital watermark embedding apparatus 102, then, converted into watermarked digital data contents 104.

The watermarked digital data contents 104 are degraded to watermarked digital data contents 105 by compression or image processing while the watermarked digital data contents 104 are distributed by wireless or wire communication or by a packaged medium.

A digital watermark reading apparatus 106 reads a watermark sequence from the degraded watermarked digital data contents 105, and reconstitutes digital watermark data 107.

In the following, a digital watermark embedding method and a digital watermark reading method by using quantization will be described, since embodiments of the present invention are based on the methods. After the description of the methods, the embodiments of the present invention will be described.

According to the digital watermarking technique based on quantization, digital watermark data is embedded by quantizing all or a part of data which is transformed (for example, by an orthogonal transform) from original digital data contents, or not-yet-transformed data. As for digital watermark data reading, data in the contents in which digital watermark data is embedded is quantized by the same value as a value used for embedding digital watermark data, and, then digital watermark data is determined from the quantized data value.

In the following, a general outline of the methods will be described. The Japanese patent application No.9-57516, "Image processing method and the apparatus", and the Japanese patent application 5 No.9-164466, "Information embedding method, data reading method and the apparatus", and the like can be referred to for obtaining detailed information of the digital watermarking technique based on quantization.

10 First, digital watermark embedding method based on quantization will be described. A process of the method is carried out by the digital watermark embedding apparatus 102 shown in Fig.1. Fig.2 is a flowchart showing the process.

15 The digital watermark embedding apparatus 102 obtains block data 109 by dividing digital data contents 103 into a plurality of blocks (m blocks in this example) in step 100. Then, a frequency coefficient matrix 115(an orthogonal transform 20 coefficient matrix) is generated by performing an orthogonal transform on the block data 108 in step 110.

A pseudo-random sequence 125 is generated from input key data 12 in step 120. Then, a 25 coefficient (for each block) from the coefficient matrix 115 is selected one by one using the pseudo-random sequence 125 so as to generate a frequency coefficient sequence 135 to be watermarked in step 130. Each bit of the digital watermark data 101 are 30 diffused by repeating number (t) of embedding so that a digital watermark sequence 145 is generated in step 140. The digital watermark sequence 145 is embedded into the frequency coefficient sequence 135 such that a watermarked frequency coefficient 35 sequence 155 is generated in step 150.

After that, the frequency coefficient sequence 135 in the frequency coefficient matrix 115

The watermark embedding process to the frequency sequence $\{f[i]\}$ is carried out as follows.

1. Following steps are carried out for all i

$$(0 \leq i < \left\lfloor \frac{m}{n} \right\rfloor \cdot n).$$

2. A watermarked frequency coefficient $f'[i]$ is obtained from the frequency coefficient $f[i]$ according to following steps.

i) If $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \bmod 2$ is equal to $s[X][Y]$,

$$f'[i] \leftarrow \left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \times q.$$

- ii) If $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \bmod 2$ is different from $s[X][Y]$ and

$$\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \text{ is equal to } \left\lfloor \frac{f[i]}{q} \right\rfloor,$$

$$f'[i] \leftarrow \left(\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor + 1 \right) \times q.$$

iii) If $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \bmod 2$ is different from $s[X][Y]$

and $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor$ is different from $\left\lfloor \frac{f[i]}{q} \right\rfloor$,

$f'[i] \leftarrow \left(\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor - 1 \right) \times q.$

Here, $X=i/t$ and $Y=i \bmod t$. In addition, $[x]$

represents a maximum number which does not exceed x and $x \bmod y$ represents the remainder of x divided by y .

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Fig.4 shows the concept of the conventional watermark embedding process. As shown in the figure, digital watermark data is embedded by changing a data value of watermarking area to a central value of the quantization width.

Next, the digital watermark reading method based on quantization will be described. The process is carried out in the digital watermark reading apparatus 106. According to the digital watermark reading process, a digital watermark data sequence is read from watermarked contents, and, then digital watermark data is reconstituted by statistically processing the digital watermark data sequence.

Fig.5 is a flowchart showing the conventional digital watermark reading process based on quantization.

The digital watermark reading apparatus 106 obtains watermarked block data 205 by dividing watermarked digital data contents 105 into a plurality of blocks (m blocks in this example) in step 200. Then, a frequency coefficient matrix 215 is generated by performing an orthogonal transform on the watermarked block data 205 in step 210.

A pseudo-random sequence 225 is generated from input key data 22 in step 220. Then, a coefficient value (for each block) of the frequency coefficient matrix 215 is selected one by one using the pseudo-random sequence 225 so as to generate a watermarked frequency coefficient sequence 235 in step 230. Then, the watermark reading process is performed on the watermarked frequency sequence 235 so that a digital watermark sequence 245 is read in step 240. Finally, the original watermark data 107 is output by performing statistical processing on the digital watermark data sequence in step 250.

Next, the digital watermark reading

process (step 240) will be described in detail with reference to a flowchart in Fig.6. The process for reading the digital watermark sequence from the watermarked frequency coefficient sequence $\{f'[i]\}$ is shown in the following.

1. Following steps are carried out for all $i(0 \leq i < \left\lfloor \frac{m}{n} \right\rfloor \cdot n)$ by using a frequency coefficient quantization width q .
2. The digital watermark sequence $s[X][Y]$ is read from the frequency coefficient $f'[i]$. That is,

$$s[X][Y] = \left\lfloor \frac{f'[i]}{q} + \frac{1}{2} \right\rfloor \bmod 2.$$

Here, $X = \left\lfloor \frac{i}{t} \right\rfloor$ $Y = i \bmod t.$

- When the digital watermark data is reconstituted from the digital watermark data sequence by performing statistical processing, a majority decision method such as

$$w[j] = \begin{cases} 1 & \sum_{k=0}^{t-1} s[j][k] \geq \frac{t}{2} \\ 0 & \sum_{k=0}^{t-1} s[j][k] < \frac{t}{2} \end{cases} \quad (0 \leq j < n)$$

is used.

- Next, the present invention corresponding to the first object will be described.

Fig.7 is a block diagram showing input data and output data of the digital watermark embedding apparatus of the present invention. The digital watermark embedding apparatus 102 inputs digital data contents 103 such as an image and a sound as main data, key data 12 and digital watermark data 101 as sub-data. The digital watermark embedding apparatus 102 embeds digital watermark data 101 into the digital data contents

Fig.2. Therefore, the different point will be mainly described in the following.

Block data 108 is input, and a complexity sequence 195 is generated by calculating a data complexity $e[i] (0 \leq e[i] \leq 1)$ for each block data in step 190. Then, the coefficient value of data to be watermarked is transformed to a value within quantization width according to the data complexity. In this embodiment, it is possible to use a conventional method for calculating the data complexity. For example, in the case of an image, a process for obtaining local image complexity can be used. In this case, it is necessary to normalize the range of the local complexity such that the range becomes from 0 to 1, if the range is from $-\alpha$ to $+\beta$.

Next, the watermark embedding process which is the heart of the second embodiment will be described in detail. Fig.10 is a flowchart showing the watermark embedding process (step 150 in Fig.9) in detail.

The process for embedding digital watermark data into a frequency coefficient sequence $\{f[i]\}$ of the first embodiment is carried out as follows.

1. For all i ($0 \leq i < \left\lfloor \frac{m}{n} \right\rfloor \cdot n$), the following process is carried out.

2. A watermarked coefficient $f'[i]$ is obtained from a coefficient $f[i]$.

1) If $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \bmod 2$ is equal to $s[X][Y]$,

$$f'[i] \leftarrow f[i] + \left(\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \times q - f[i] \right) \times e[i]$$

ii) If $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \bmod 2$ is not equal to $s[X][Y]$ and

$\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor$ is equal to $\left\lfloor \frac{f[i]}{q} \right\rfloor$,

$$f'[i] \leftarrow \left(\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor + \frac{e[i]+1}{2} \right) \times q$$

iii) If $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor \bmod 2$ is not equal to $s[X][Y]$ and

5 $\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor$ is not equal to $\left\lfloor \frac{f[i]}{q} \right\rfloor$,

$$f'[i] \leftarrow \left(\left\lfloor \frac{f[i]}{q} + \frac{1}{2} \right\rfloor - \frac{e[i]+1}{2} \right) \times q.$$

Here, q represents the quantization width for digital watermark data embedding, $X=i/j, Y=i \bmod t$, and $\lfloor x \rfloor$ is the maximum integer which does not exceed x ,

10 and $x \bmod y$ represents the remainder of x divided by y .

Figs.11A and 11B are conceptual diagrams showing the digital watermark embedding process of the first embodiment. As shown in Fig.11B, a data complexity $e[i] (0 \leq e[i] \leq 1)$ is calculated for each block data, then, the value of data in which digital watermark data is embedded is transformed to a value within the quantization width according to the data complexity.

20 Generally, the quality of the watermarked digital data contents is a trade-off for the strength of the digital watermark data. However, according to the present invention, both of the quality of the watermarked digital data contents and

2. For all $(v_0, v_1, \dots, v_{N-1})$, a step 3 is carried out (N dimensional loop).

3. For a threshold $\Delta \geq 0$ which is set beforehand,
If $|hv_0, v_1, \dots, v_{N-1}| \geq \Delta$, $\text{count} \leftarrow \text{count} + 1$. Here, $|x|$
5 | represents the absolute value of x .

4. For a threshold $\Gamma \geq 0$ which is set beforehand,
If $\text{count} \geq \Gamma$, $e[i] \leftarrow 1.0$. If not, $e[i] \leftarrow \frac{\text{count}}{\Gamma}$.

In the process for calculating the data complexity, for example, if it is assumed that $N=2$
10 (an image), the basis of the wavelet transform is the Haar basis, $M_0=16$ and $M_1=16$, an experiment shows that values of $\Delta=4$ and $\Gamma=16$ are good for the balance for embedding digital watermark data without being notified by a human.

15 According to the second embodiment, the above-mentioned function can be realized by setting the two thresholds Δ and Γ according to the characteristics of the watermarking technique such as the kind of data to be watermarked, a unit (the
20 size of the block data), the kind of orthogonal transform to be used. By applying the above-mentioned function to the watermarking technique, it becomes possible to embed digital watermark data more appropriately according to characteristics of
25 individual digital data contents.

(Third Embodiment)

In the following, a fourth embodiment of the present invention will be described.

30 According to the third embodiment, in the digital watermark embedding process, block data of digital data contents is obtained, and a transformation amount of frequency coefficient is calculated on the basis of a transformation amount for each frequency band according to a manipulation
35 method of the digital data contents. Then, block data of the watermarked digital data contents is

generated.

Let the dimension of a block data $B[i]$ be N and the size be $M_0 \times M_1 \cdots \times M_{N-1}$. Here, a sequence which represents the ratio of transformation width for the frequency band of each frequency coefficient needs to be obtained beforehand by using adequate digital data contents before operating a digital watermarking system. The calculation method for obtaining $q[i]$ will be described in detail in a fifth embodiment later.

Fig.13 is a flowchart for obtaining the ratio of the quantization with for each frequency band. First, digital data contents 1000 is input, and block data 1015 is obtained by dividing the input digital data contents into blocks in step 1010. The block data 1015 is transformed to first frequency coefficient matrices by applying the orthogonal transform in step 1020. Next, digital data contents 1035 is generated by performing a manipulation such as non-reversible compression on the digital data contents 1000 in step 1030. Then, block data 1045 is generated by dividing the digital data contents 1035 into blocks in step 1040. Second frequency matrices 1055 is generated by applying the orthogonal transform to the block data 1015 in step 1055. Then, the variance of the distribution of the difference between each element of the frequency coefficients matrices 1025 and each element of the frequency coefficients matrices 1055 is obtained in step 1060. Finally, watermark weight ratio data v_0, v_1, \dots, v_{N-1} 1070 which represents the ratio of transformation for each frequency coefficient is obtained. The watermark weight ratio data obtained in this way is stored, and it is used in a watermark embedding process and a watermark reading process as necessary. The quantization width is obtained as $d_{v_0, v_1, \dots, v_{N-1}} \times \text{Power}$ which will be described next.

Fig.14 is a flowchart showing the watermark embedding process which is the heart of the third embodiment of the present invention. Here, the flow of the whole process is the same as that shown in Fig.2 or Fig.9.

Let the watermark weight ratio sequence be $\{dv_0, v_1, \dots, v_{N-1}\}$ ($0 \leq v_u < M_u, 0 \leq u < N$), and let the watermark strength be Power (the watermark strength represents durability of digital watermark data against manipulations of watermarked digital data contents.)

The watermark embedding process of the embodiment is carried out as follows.

1. For all i ($0 \leq i < \left\lfloor \frac{m}{n} \right\rfloor \cdot n$), a following process is carried out.
2. A quantization width $q[i]$ used when embedding digital watermark data into the frequency coefficient $f[i]$ is obtained by $q[i] \leftarrow dv_0, v_1, \dots, v_{N-1} \times \text{Power}$ by using an element $dv_0, v_1, \dots, v_{N-1}$ of the watermark weight ratio sequence which corresponds to the band of the frequency coefficient $f[i]$ ($f[i]$ is a $(v_0, v_1, \dots, v_{N-1})$ th component of the frequency coefficient matrices).
3. The watermarked frequency coefficient $f'[i]$ is obtained from the frequency coefficient $f[i]$ in the following way.

$$i) \text{ If } \left\lfloor \frac{f[i]}{q[i]} + \frac{1}{2} \right\rfloor \bmod 2 \text{ is equal to } s[X][Y],$$

$$f'[i] \leftarrow \left\lfloor \frac{f[i]}{q[i]} + \frac{1}{2} \right\rfloor \times q[i].$$

$$ii) \text{ If } \left\lfloor \frac{f[i]}{q[i]} + \frac{1}{2} \right\rfloor \bmod 2 \text{ is not equal to } s[X][Y] \text{ and}$$

strength represents durability of digital watermark data against manipulations such as non-reversible compression to watermarked digital data contents.)

The process for reading the digital

- 5 watermark data sequence from the watermarked frequency coefficient according to the fourth embodiment is carried out as follows.

1. For all i ($0 \leq i < \left\lfloor \frac{m}{n} \right\rfloor \cdot n$), a following process is carried out.

2. A quantization width $q[i]$ used when reading digital watermark data from the frequency coefficient $f'[i]$ is obtained by $q[i] \leftarrow dv_0, v_1, \dots, v_{N-1} \times$ Power by using an element $dv_0, v_1, \dots, v_{N-1}$ of the watermark weight ratio sequence which corresponds to the band of frequency coefficient $f[i]$ ($f[i]$ is a $(v_0, v_1, \dots, v_{N-1})$ th component of the frequency coefficient matrices).

3. The digital watermark data sequence $s[X][Y]$ is read from the watermarked frequency coefficient $f'[i]$ in the following way.

$$s[X][Y] \leftarrow \left\lfloor \frac{f'[i]}{q[i]} + \frac{1}{2} \right\rfloor \bmod 2$$

Here, $X = \left\lfloor \frac{i}{t} \right\rfloor$ and $Y = i \bmod t$.

- According to the above-mentioned third and fourth embodiment, the watermark embedding strength can be changed according to the frequency band. Specifically, the watermark embedding and reading method applicable for a manipulation method becomes possible. In the method, according to the amount of change of digital data contents from original data for each frequency band due to manipulation such as non-reversible compression, the watermark strength is raised to a band when the amount is large, and the watermark strength is reduced when the amount is

small. Accordingly, both of the quality of watermarked digital data contents and the durability of digital watermark data can be improved at a time.

(Fifth Embodiment)

5 In the following, a fifth embodiment of the present invention will be described. According to the fifth embodiment, a number of digital data contents (images, sounds and the like) are prepared and calculation of a watermark strength matrix is
10 carried out for each frequency band.

A processing flow of the fifth embodiment is the same as that shown in Fig.13 basically. Here, the orthogonal transform process shown in Fig.13 is the same as an orthogonal transform process used for
15 digital watermarking process. For example, if the orthogonal transform used for digital watermarking is discrete cosine transformation (DCT) for a 16×16 size, the DCT is used, and, if the transformation used for digital watermarking is fast Fourier
20 transform (FFT) for an 128×128 size, the FFT is used.

Fig.16 is a flowchart showing the process of calculating the watermark strength matrix for each frequency band according to the fifth
25 embodiment.

Here, let the frequency coefficient matrices be N , the size be $M_0 \times M_1 \times \dots \times M_{N-1}$, and each of the components be $x_{v_0, v_1, \dots, v_{N-1}}$, $xt_{v_0, v_1, \dots, v_{N-1}} (0 \leq v_i < M_i, 0 \leq u < N)$. The process shown in Fig.16 is as follows.

30 1. For all $i (0 \leq i < m)$, the following steps 2 and 3 are performed.

2. For all $(v_0, v_1, \dots, v_{N-1}) = (0, 0, \dots, 0) \sim (M_0, M_1, \dots, M_{N-1})$, the process of the following step 3 is performed.

$$3. y_{v_0, v_1, \dots, v_{N-1}}^{(i)} \leftarrow x_{v_0, v_1, \dots, v_{N-1}} - xt_{v_0, v_1, \dots, v_{N-1}}$$

35 4. For all $(v_0, v_1, \dots, v_{N-1}) = (0, 0, \dots, 0) \sim (M_0, M_1, \dots, M_{N-1})$, the

following steps 5 and 6 are performed.

$$5. \quad A_{v_0, v_1, \dots, v_{N-1}} \leftarrow \frac{\sum_{i=0}^{m-1} y_{v_0, v_1, \dots, v_{N-1}}^{(i)}}{m}$$

$$6. \quad d_{v_0, v_1, \dots, v_{N-1}} \leftarrow \sqrt{\frac{\sum_{i=0}^{m-1} (y_{v_0, v_1, \dots, v_{N-1}}^{(i)} - A_{v_0, v_1, \dots, v_{N-1}})^2}{m}}$$

According to the fifth embodiment, it becomes possible to set the watermark strength to a level that is suitable for each frequency band according to a manipulation method for digital data contents such as non-reversible compression. For example, if the watermark strength is Power and the distribution of the amount of change of each coefficient value of the frequency coefficients after a manipulation can be approximated by a Laplacian distribution, when digital watermark data is read from digital data contents on which an assumed manipulation is performed, the rate of bit reversal for the extracted digital watermark data

can be made constant $e^{-\frac{\text{Power}}{\sqrt{2}}}$ regardless of the frequency band (e is the natural logarithm). It is the advantage of the present invention to be able to predict the rate of bit reversal with the constant formula. In addition, according to the embodiment of the present invention, one of the problem of the conventional method that durability of embedded digital watermark data is varied according to the position of the frequency coefficient is solved. That is, the durability of the embedded digital watermark data is constant regardless of the position of the frequency coefficient (which is obvious from the above formula). The embodiment can be applied not only to the watermarking method based on quantization but also to a watermarking method

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based on the spread spectrum technique.

(Sixth Embodiment)

In the following, a sixth embodiment of the present invention will be described. According to the sixth embodiment, the digital watermark embedding process is carried out by utilizing the first embodiment and the third embodiment in combination. The watermark embedding process of the sixth embodiment will be described as a modification of the step 150 shown in Fig.9.

According to the sixth embodiment, the process for embedding digital watermark data in a frequency coefficient sequence $\{f[i]\}$ is as follows.

1. For all i ($0 \leq i < \left\lfloor \frac{m}{n} \right\rfloor \cdot n$), the following is performed.

2. A quantization width $q[i]$ used when embedding digital watermark data into the frequency coefficient $f[i]$ is obtained by $q[i] \leftarrow dv_0, v_1, \dots, v_{n-1} \times$ Power by using an element $dv_0, v_1, \dots, v_{n-1}$ of the watermark weight ratio sequence which corresponds to the band of the frequency coefficient $f[i]$.

3. The watermarked coefficient $f'[i]$ is obtained from the frequency coefficient $f[i]$ in the following way.

i) If $\left\lfloor \frac{f[i]}{q[i]} + \frac{1}{2} \right\rfloor \bmod 2$ is equal to $s[X][Y]$,

$$f'[i] \leftarrow f[i] + \left(\left\lfloor \frac{f[i]}{q[i]} + \frac{1}{2} \right\rfloor \times q[i] - f[i] \right) \times e[i].$$

ii) If $\left\lfloor \frac{f[i]}{q[i]} + \frac{1}{2} \right\rfloor \bmod 2$ is not equal to $s[X][Y]$ and

$$\left\lfloor \frac{f[i]}{q[i]} + \frac{1}{2} \right\rfloor \text{ is equal to } \left\lfloor \frac{f[i]}{q[i]} \right\rfloor,$$

unit 305. The digital watermarking process of the present invention is carried out by running the program stored in the memory 301 on the CPU 300.

In addition, the digital watermark reading apparatus and the digital watermark embedding apparatus can be realized also by an integrated circuit shown in Fig.18. The integrated circuit includes a memory part 401, a micro processor part 402, an interface part 403 managing an interface to an outside part. Since, the configuration in Fig.18 shows principal parts, the integrated circuit may include other parts. The program stored in the memory part 401 is carried out by a micro processor part 402. The integrated circuit can take various other configurations. The integrated circuit can be incorporated to various apparatuses such as a camera so that the apparatuses can perform the digital watermarking process of the present invention.

As mentioned above, according to the present invention, the rate of the amount of change of frequency coefficients is changed, and/or, the amount of change of rate is increased or decreased according to the complexity of the digital data contents. Therefore, the quality of the watermarked digital data contents can be improved and the durability of digital watermark data against a manipulation of the watermarked digital data contents can be improved.

Next, embodiments of the present invention corresponding to the second objectives will be described.

(Seventh Embodiment)

In the following, the seventh embodiment of the present invention will be described with reference to figures.

Fig.19 is a block diagram of a digital watermarking system to which the present invention

relates. Fig.19 shows a similar configuration to that shown in Fig.1. The difference is that Fig.19 shows a digital watermark data reconstitution apparatus 108 which is an essential part of the present invention. The digital watermark data reconstitution apparatus 108 is provided in the watermark embedding apparatus 106. In the system, a digital watermark data sequence is read from the watermarked digital data contents 105 by using the watermark reading apparatus 106. Then, the digital watermark data sequence is processed in the digital watermark data reconstitution apparatus 108 so that the read digital watermark data 107 is obtained.

In the following, the process for reconstituting the digital watermark data is described in detail.

Fig.20 is a block diagram of the watermark reading apparatus 106. The digital watermark data reconstitution apparatus 108 provided in the watermark reading apparatus 106 obtains the probability q that bit 1 is read when any 1 bit watermark sequence is read from a whole watermark area beforehand by using the watermark reading apparatus 106.

Specifically, assuming a 1 bit watermark sequence reading part 501, the part 501 reads the watermark sequence 1 bit by 1 bit from all elements of the whole watermark area (a broken line L1), and calculates the ratio of the number of bit 1 to the number of all trials.

In the embodiment, the reading probability of bit 1 and the number of bit 1 are obtained. However, it is possible that the reading probability of bit 0 and the number of bit 0 are obtained. Basically, there is no difference between the former and the latter. The difference is only on implementation.

Accordingly, the probabilities of detecting bit 0 and 1 when reading 1 bit at random in the watermark area by using the digital watermarking algorithm is calculated to be $1-q$ and q respectively.

The n bit watermark sequence reading part 502 reads the digital watermark data sequence from the watermarked digital data contents for the number of total times of embedding digital watermark data.

Here, digital watermark data is defined as $b_0, b_1, \dots, b_{m-1}, b_i \in \{0, 1\}, i < m$ (m bit length), the repeating number of embedding i th bit of the digital watermark data in the digital data contents is defined as n_i , the read watermark sequence is defined as

$b'_{0,0}, b'_{0,1}, \dots, b'_{0,n_0-1}, b'_{1,0}, b'_{1,1}, \dots, b'_{1,n_1-1}, \dots, b'_{m-1,0}, b'_{m-1,1}, \dots, b'_{m-1,n_{m-1}-1} \quad b_{i,j} \in \{0, 1\} \quad (\sum_{r=0}^{m-1} n_r \text{ bit length}).$

The data reconstitution apparatus 108 receives a subsequence of the digital watermark data sequence one after another from a subsequence corresponding to 0th digital watermark data to a subsequence corresponding to $(m-1)$ th digital watermark data (a solid line L2).

Next, the method for reconstituting i th bit of the digital watermark data will be described concretely.

When n_i bits of digital watermark data sequence is read at random from the watermark area, the probability $P(x=k)$ of k '1' bits appearing in the n_i bit sequence is represented by the binary distribution density function

$$P(x=k) = n_i C_k q^k \cdot (1-q)^{n_i-k} \quad (1)$$

and the distribution function of that, $F(x)$, is

$$F(x) = \sum_{k=0}^x n_i C_k q^k \cdot (1-q)^{n_i-k} \quad (0 \leq x \leq n_i). \quad (2)$$

Here, $n_i C_k$ is the number of combinations when selecting k out of n_i .

Setting a reliability threshold value α ($1/2 < \alpha \leq 1$) of the digital watermark data, the number of bit 1 included in a subsequence $b'_{i,0}, b'_{i,1}, \dots, b'_{i,n_i-1}$ corresponding to i th digital watermark data is calculated by

$$k_i = \sum_{r=0}^{n_i-1} b'_{i,r}.$$

Then, digital watermark data is determined in the following way by using the formula (2):

$$b_i = \begin{cases} 0 & \text{when } 0 \leq F(k_i) \leq 1-\alpha \\ 1 & \text{when } \alpha \leq F(k_i) \leq 1 \\ \text{unknown or not present} & \text{when } 1-\alpha < F(k_i) < \alpha \end{cases} \quad (3)$$

Viewing from a different angle, when determining by the number of bit 1 included in the watermark sequence n_i , if the largest integer x_0 that satisfies $0 \leq F(x = x_0) \leq 1-\alpha$ and the smallest integer x_1 that satisfies $\alpha \leq F(x = x_1) \leq 1$ are assumed to be threshold values, the digital watermark data is judged as shown in Fig.21 such that if the number of 1 in n_i is equal to or smaller than x_0 , the digital watermark data is 0, and that if the number of 1 is equal to or larger than x_1 , the digital watermark data is 1.

The horizontal axis of Fig.21 represents the number of bit 1 included in the watermark sequence, and the vertical axis represents frequency of the corresponding number. As for unwatermarked digital data contents, the frequency that bit 1 appears in a bit sequence read at random from the digital data contents becomes binary distribution. Thus, the peak of the frequency is at the half point of the number of bits. On the other hand, as for watermarked contents, in the subsequence n_i in which

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bit 0 is embedded as digital watermark data, the frequency of bit 1 is 0 if there is no degradation and it is a small number which is equal to or smaller than x_0 , even if there is degradation. In the subsequence n_i in which bit 1 is embedded as digital watermark data, the frequency of bit 1 is n_1 if there is no degradation and it is a large number which is equal to or larger than x_1 , even if there is degradation. In this way, the distribution of the frequency of bit 1 or bit 0 in the watermarked sequence is leaning to one side from the center of the binary distribution. The present invention uses the lean for reconstituting digital watermark data from the read watermark sequence.

Depending on a watermarking system, a following method can be used. That is, reconstituted digital watermark data is obtained by using the bias from the central value of the distribution $P(x)$ of the watermark sequence extracted from digital data contents 105. Next, the probability of appearing the read watermark sequence is calculated by the formula (2). Then, if the reconstituted digital watermark data is 1, $F(k_1)$ can be added to watermark data as the reliability, and, if the reconstituted digital watermark data is 0, $1-F(k_1)$ can be added. The reliability $F(k_1)$ and $1-F(k_1)$ of the digital watermark data is obtained from the bias of appearance probability of the digital watermark data in the binary distribution of appearance probability of each bit of 1 bit sequence extracted at random from digital data contents.

Fig.22 shows a concept in which the length of the digital watermark data is extended to m bits.

The digital watermark data reconstitution apparatus 108 outputs the reconstituted digital watermark data b_0, b_1, \dots, b_{m-1} as read digital watermark data 107.

the same pseudo-random sequence is necessary for digital watermark data reading.

For example, if 1 bit watermark sequence is read by using an M-sequence as the pseudo-random sequence, it becomes $q=1/2$. Therefore, the present invention can be applicable without depending on the watermarking algorithm and digital data contents.

When digital watermark data reading,
demodulation is carried out as $b'_{i,j} = m_{i,j} (+) r_{i,j}$
10 by using a pseudo-random sequence generator (B) 602
which is provided in the watermark reading apparatus
106.

Here, the pseudo-random sequence generator (A) 601 and the pseudo-random sequence generator (B) 602 needs to be implemented such that both of the generators generate the same pseudo-random sequence.

Watermark data is reconstituted with the method of the seventh embodiment from the watermark sequence $b'_{0,0}, b'_{0,1}, \dots, b'_{0,n-1}, b'_{1,0}, b'_{1,1}, \dots, b'_{1,n-1}, \dots, b'_{m-1,0}, b'_{m-1,1}, \dots, b'_{m-1,n-1}$ obtained by the demodulation.

Since it is considered that the appearance probability q of bit 1 in the watermark sequence can be approximated by the binary distribution
25 regardless of the presence or absence of modulation, there is no influence on the distribution of the density function (1) due to the modulation shown in this embodiment.

30 In addition, $q=1/2$ can be assumed in
implementation, that is, no process is necessary for
obtaining q . Therefore, the amount of processing
that is required for watermark reconstitution thus
becomes the same as that for majority decision
35 processing. Thus, the reconstitution process
becomes faster.

(Ninth Embodiment)

$b'_{0,0}, b'_{0,1}, \dots, b'_{0,n0-1}, b'_{1,0}, b'_{1,1}, \dots, b'_{1,n-1}, \dots, b'_{m,0}, b'_{m,1}, \dots, b'_{m,n-1}$ which is read from digital data contents will be described in the following with reference to Fig.25.

- 5 The watermark sequence is read with respect to each bit value from the digital data contents and key data necessary for digital watermark data reading in step 1.

- 10 The threshold value α ($1/2 < \alpha \leq 1$) of the reliability is set in step 2. For example, if the reliability of read digital watermark data needs to be equal to or more than 99%, it is set as $\alpha = 0.99$.

- 15 The probability q of bit '1' when 1 bit of the watermark sequence is read at random from the whole watermark area of watermarked digital data contents is obtained beforehand in step 3. The appearance probabilities of bits '0' and '1' are calculated as $1-q$ and q respectively.

- 20 The probability that x bits of '1' are included in the watermark sequence of each bit data of digital watermark data are obtained as

$$F(x) = \sum_{j=0}^x {}^nC_j q^j \cdot (1-q)^{n-j}$$

by using the binary distribution function in step 4.

- 25 It is checked in step 5 that the probability that n bit digital watermark data sequence is digital watermark data exceeds the threshold value α . Specifically, it is checked whether the following formula (4) is satisfied.

$$F\left(\frac{\sum_{i=0}^{m-1} \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2}}{m} + \frac{n}{2}\right) \geq \alpha \quad (4)$$

- 30 Here, $|a|$ represents the absolute value of a .

$\sum_{j=0}^{n-1} b_{1,j} - n/2$ represents the bias from the center of

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the binary distribution of the number of bit '1' in the n bit watermark sequence. $\sum_{j=0}^{m-1}$ of $\sum_{j=0}^{n-1} b_{i,j} - n/2$ divided by m represents the average for the m bits of the whole digital watermark data. n/2 represents the center of the binary distribution.

If the formula (4) is true, it is judged that there is digital watermark data. Thus, in each n bit watermark sequence of m digital watermark data sequences, digital watermark data is reconstituted by a majority decision processing.

Specifically, if it is judged that there is digital watermark data, digital watermark data is reconstituted in the following way in step 6.

For all i ($0 \leq i < m$),

when $\sum_{j=0}^{n-1} b_{i,j} < n/2 : w'_i = 0$,

when $\sum_{j=0}^{n-1} b_{i,j} \geq n/2 : w'_i = 1$.

This process is carried out by steps 6-1 - 6-7 in Fig.25.

$$\text{If } F \left(\frac{\sum_{i=0}^{m-1} \left| \sum_{j=0}^{n-1} b_{i,j} - \frac{n}{2} \right|}{m} + \frac{n}{2} \right) < \alpha,$$

it is judged that there is no watermark data or the presence or absence is unknown. A following formula (5) can be used instead of the formula (4).

$$F \left(\frac{n}{2} - \frac{\sum_{i=0}^{m-1} \left| \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2} \right|}{m} \right) \leq 1 - \alpha \quad (5)$$

If the formula (5) is not true, it is judged that there is no watermark data or the presence or absence unknown.

According to the tenth embodiment, statistical processing for whole watermark sequence is carried out so as to judge the presence or absence of watermark by using the formula (4) or the formula (5). If it is judged that there is digital watermark data, the reconstitution is carried out by the majority decision processing. Therefore, even if there is one bit of low reliability, digital watermark data can be reconstituted.

In Fig.25, the step 1 can be carried out between the steps 4 and 5.

The tenth embodiment may use the pseudo-random sequence which is described in the eighth embodiment. Specifically, watermark embedding is carried out by modulating digital watermark data sequence with the pseudo-random sequence. When reconstituting, the read digital watermark data sequence is demodulated by the pseudo-random sequence, then the judgment by the formula (4) is performed. If the result is more than α and there is digital watermark data, the reconstitution process of the majority decision is performed on the demodulated sequence, which is the same process as the step 6 of the eleventh embodiment. The whole process is shown in Fig.26, adding the same reference symbol to the corresponding part shown in Fig.25. In the example, the pseudo-random sequence $\{r_{i,j}\}$ is generated from key data 'Key' and the process goes to step 2 in step 8. Next to step 4, watermark sequence is demodulated with the pseudo-random sequence $\{r_{i,j}\}$ in step 9. The watermark bit $b'_{i,j}$ in the formula (4) in step 5 is a bit which is demodulated in step 9. Also, the majority decision processing in step 6 is performed on $b'_{i,j}$.

(Eleventh Embodiment)

In the following, a eleventh embodiment will be described.

Then, the digital watermark data is reconstituted.

$$\text{If } \frac{\sum_{i=0}^{m-1} \left| \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2} \right|}{m} + \frac{n}{2} < x_1,$$

it is judged that there is no watermark data or the presence or absence is unknown.

5 In the above process, it is possible to
use the maximum integer x_0 which satisfies $F(x=x_0) \leq$
1- α instead of the minimum integer x_1 which
satisfies $F(x=x_1) \geq \alpha$. In this case, a formula for
judging the presence or absence of watermark is
0 shown below as a formula (7).

$$\frac{n}{2} - \frac{\sum_{i=0}^{m-1} \left| \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2} \right|}{m} \leq x_0 \quad \cdots (7)$$

If the left part of the formula is more than x_0 , it is judged that there is no watermark data or the presence or absence is unknown.

15 (Twelfth Embodiment)

In the following, a twelfth embodiment of the present invention will be described.

When it is judged that there is digital watermark data by the formula (4), the digital watermark data is reconstituted by the above-mentioned majority decision process. At the same time, the reliability of the reconstituted watermark sequence as a whole is calculated as

$$F \left(\frac{\sum_{i=0}^{m-1} \left| \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2} \right|}{m} + \frac{n}{2} \right)$$

25 and it is output.

Similarly, when it is judged that there is digital watermark data by the formula (5) and the

digital watermark data is reconstituted, the reliability of the reconstituted digital watermark data sequence as a whole is calculated as

$$F \left(\frac{n}{2} - \frac{\sum_{i=0}^{m-1} \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2}}{m} \right)$$

5 and it is output.

When it is judged that there is digital watermark data by the formula (6), the digital watermark data is reconstituted by the above-mentioned majority decision process. At the same
10 time, the reliability of the reconstituted watermark sequence as a whole is calculated as

$$F \left(\frac{\sum_{i=0}^{m-1} \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2}}{m} + \frac{n}{2} \right)$$

and it is output.

Similarly, when it is judged that there is
15 digital watermark data by the formula (7), the reliability of the digital watermark data as a whole is calculated as

$$F \left(\frac{n}{2} - \frac{\sum_{i=0}^{m-1} \sum_{j=0}^{n-1} b'_{i,j} - \frac{n}{2}}{m} \right)$$

and it is output.

20 In the above-mentioned seventh - twelfth embodiments, the reading probability of bit 1 and the number of bit 1 are obtained. However, it is possible that the reading probability of bit 0 and the number of bit 0 are obtained. Basically, there
25 is no difference between the former and the latter.

The difference is only on implementation.

In the following, examples of experiments will be shown. In the following experiments, an image of "lena" which has 128×128 pixels is used as a test image, and the threshold value α of the reliability is assumed to be 0.999999.

(First Experiment)

In this experiment, 1 bit digital watermark data '1' was embedded 127 times repeatedly using key data '50,000', and the watermark sequence was read with various key data. Fig.27 shows the number of bit '1' in the read watermark sequence corresponding to the key data. In Fig.27, the vertical axis shows the number of bit '1' in the read watermark sequence, and the horizontal axis shows the key data value. In this experiment, the appearance frequency of bit '1' in the watermark area A was $q=0.492247$.

When correct key data (50,000) is used, it is judged that digital watermark data is '1' with 99.9999% correctness since the number of bit '1' is more than the threshold value X_1 for judging the presence of watermark. When incorrect key data is used, it is judged that there is no watermark data or the presence or absence is unknown.

(Second Experiment)

In the second experiment, a watermark sequence which was modulated with a 7 stage M-sequence (initial state is 64) was embedded, and a similar experiment as the first experiment was carried out with various key data and M-sequences of various initial states. The result is shown in Fig.28. By carrying out the modulation, the value of q becomes 0.500000 from 0.492247, and the variance becomes 31.718777 from 31.008265. Thus, the values are almost not changed from those of the first experiment. It is only when correct key data

for watermark reconstitution becomes the same as that for majority decision processing. Thus, the speed of the processing becomes higher.

α is an index which represents a lower
5 limit of the correctness rate of read digital watermark data, and is manageable in the digital watermarking system. Therefor, the method of using α is superior to a conventional method of showing the correctness rate of read digital watermark data
10 to a user.

According to the seventh embodiment, if there is even one bit of low reliability in digital watermark data $\{w'_i\}$, it is judged that there is no watermark data or the presence or absence is unknown.
15 However, even in the case, according to the eleventh - thirteenth embodiments, the reliability of digital watermark data can be evaluated quantitatively, the probability for reading digital watermark data incorrectly can be suppressed within $2(1-\alpha)$, and
20 the digital watermark data can be reconstituted. In the tenth - twelfth embodiments, the whole digital watermark data is statistically processed by modifying the formula for judging the presence or absence of digital watermark data, since digital
25 watermark data can be reconstituted in many cases, when watermark sequence $\{b'_{i,j}\}$, ($0 \leq i < m, 0 \leq j < n$) is seen statistically as a whole.

In addition, according to the seventh embodiment, $F(\sum_{j=0}^{n-1} b'_{i,j})$ needs to be calculated
30 with the distribution function $F(x)$ of the binary distribution for all i to reconstitute digital watermark data from watermark sequence. On the other hand, according to the tenth - twelfth
35 embodiments, only one calculation using the distribution function is necessary so that the amount of processing can be reduced.

corresponding to the third object will be described in detail.

First, the operation of the digital watermark reading apparatus 106 will be described.

5 Fig.33 is a diagram for explaining the operation. As shown in Fig.33, the process according to the present invention corresponds to the process shown in Fig.5 in which steps 240 - 250 are improved.

10 As shown in Fig.33, in the digital watermark reading apparatus 106, when reading

digital watermark, $v[X][Y] = \text{weight} \left(\frac{f'[Y]}{q[i]} \right) - Z \times \{(Z \bmod 2) - 1\}$,

for all i ($0 \leq i < \left\lfloor \frac{m}{n} \right\rfloor \cdot n$), by using frequency

coefficient quantization width $q[0], q[1], \dots, q[m-1]$. Here,

15 $X = \left\lfloor \frac{i}{t} \right\rfloor$, $Y = i \bmod t$, $Z = \left\lfloor \frac{f'[i]}{q[i]} + \frac{1}{2} \right\rfloor$. The function

weight will be described later.

In the process for reconstituting digital watermark data by performing statistical processing on a digital watermark data sequence, for example,

$$20 \quad w[j] = \begin{cases} 1 & \sum_{k=0}^{t-1} v[j][k] \geq 0 \\ 0 & \sum_{k=0}^{t-1} v[j][k] < 0 \end{cases} \quad (0 \leq j < n)$$

is used for the reconstitution.

(Thirteenth Embodiment)

In the following, a thirteenth embodiment of the present invention will be described. In the
25 following example, the digital watermark reading process based on quantization in the digital watermark reading apparatus 106 will be described.

According to the thirteenth embodiment of the present invention, the digital watermark

embedding process is not changed from the conventional method. On the other hand, the digital watermark reading process is modified in order to improve digital watermark reading performance.

5 Here, let digital watermark data to be embedded in contents be $w_0, w_1, \dots, w_{n-1}, w_i \in \{-1, 1\}$, $0 \leq i \leq n-1$, and let a data set in which digital watermark data is embedded be $\{d_{0,0}, d_{0,1}, \dots, d_{0,m-1}, d_{1,0}, d_{1,1}, \dots, d_{1,m-1}, \dots, d_{n-1,1}, \dots, d_{n-1,m-1}\}$. Let a quantization value used for quantize data $d_{i,j}$ ($0 \leq i \leq n-1, 0 \leq j \leq m-1$) be $q_{i,j}$. Each bit data w_i of digital watermark data is embedded m times repeatedly. The digital watermark embedding process based on quantization is assumed to be a process in the following.

For all i and j ($0 \leq i \leq n-1$, $0 \leq j \leq m-1$)

1) If $\left[\frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right] \bmod 2$ is equal to w_i , $d_{i,j}$ is changed to $\left[\frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right] \times q_{i,j}$.

ii) If $\left| \frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right| \bmod 2$ is different from w_1 and

20 $\left| \frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right|$ is equal to $\left| \frac{d_{i,j}}{q_{i,j}} \right|$, $d_{i,j}$ is changed to

$$\left(\left\lfloor \frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right\rfloor + 1 \right) \times q_{i,j}.$$

iii) If $\left| \frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right| \bmod 2$ is different from w_i and

$\left| \frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right|$ is different from $\left| \frac{d_{i,j}}{q_{i,j}} \right|$, $d_{i,j}$ is changed to

$\left(\left\lfloor \frac{d_{i,j}}{q_{i,j}} + \frac{1}{2} \right\rfloor - 1 \right) \times q_{i,j}$. Here, $\lfloor x \rfloor$ is a maximum number which does not exceed x . " $x \bmod y$ " represents the remainder of x divided by y .

The present invention is not only applicable to the contents in which digital watermark data is embedded in the above-mentioned way but also applicable to other contents in which digital watermark data is embedded in other equivalent way.

In the following, the operation of the digital watermark reading apparatus 106 will be described in detail.

According to a following process, a watermark sequence

$\{\tilde{w}_{0,0}, \tilde{w}_{0,1}, \dots, \tilde{w}_{0,m-1}, \tilde{w}_{1,0}, \tilde{w}_{1,1}, \dots, \tilde{w}_{1,m-1}, \dots, \tilde{w}_{n-1,0}, \tilde{w}_{n-1,1}, \dots, \tilde{w}_{n-1,m-1}\}$ is read from a set of data values $\{\tilde{d}_{0,0}, \tilde{d}_{0,1}, \dots, \tilde{d}_{0,m-1}, \tilde{d}_{1,0}, \tilde{d}_{1,1}, \dots, \tilde{d}_{1,m-1}, \dots, \tilde{d}_{n-1,0}, \tilde{d}_{n-1,1}, \dots, \tilde{d}_{n-1,m-1}\}$ of the watermarked digital data contents 105 in which digital watermark data is embedded.

For all i and j ($0 \leq i \leq n-1$, $0 \leq j \leq m-1$)

$$n_{i,j} = \left\lfloor \frac{\tilde{d}_{i,j}}{q_{i,j}} + \frac{1}{2} \right\rfloor \quad \text{and}$$

$$\tilde{w}_{i,j} = \text{weight} \left(\frac{\tilde{d}_{i,j}}{q_{i,j}} - n_{i,j} \right) \times \{ (n_{i,j} \bmod 2) \times 2 - 1 \}.$$

Here, $\text{weight}(x)$ (the domain is $-\frac{1}{2} \leq x \leq \frac{1}{2}$, and the range is equal to or more than 0. The function $\text{weight}(x)$ will be called a weight function hereinafter) is a function which assigns weights to a read watermark sequence. By adopting a function which takes a large value in the vicinity of the

central value (in the vicinity of the dotted vertical axis in Fig.30) and takes a small value in the vicinity of the boundary of the bit value (in the dotted circle in Fig.30), it becomes possible to
5 separate effective watermark data sequence from noise.

Of course, it is possible to adopt a stretched weight(x) function in which the domain and the region is not limited. However, in the case, it
10 is necessary to change the above mentioned formula to some extent.

Contents in which digital watermark data is embedded by digital watermark embedding processing is degraded due to data compression, media processing and the like. Thus, a watermark
15 embedded data value $\tilde{d}_{i,j}$ deviates in some degree from a value $d_{i,j}$ of immediately after being embedded. Therefore, it is desirable to adopt a following function as the weight function. The function can
20 be obtained such that the distribution of the ratio

$$\frac{\tilde{d}_{i,j} - d}{q_{i,j}}$$

of the amount of the deviation between $d_{i,j}$

and $\tilde{d}_{i,j}$ to the quantization value $q_{i,j}$ is predicted, and it is normalized with an appropriate scale for approximation. (There is no condition for the
25 scale.)

For example, when assuming that digital watermark data is read from watermarked motion pictures which are MPEG compressed, the distribution shown in Fig.30 can be approximated by a Laplacian
30 distribution. Thus, a Laplacian distribution of average 0 and variance 0.08 or a normal distribution of average 0 and variance 1/16 can be used effectively as the weighting function.

In addition, there is another method which uses another distribution function. The distribution function is formed so as to predict the error of the watermarked content data.

- 5 The digital watermark reading apparatus 106 reconstitutes and outputs digital watermark data $\tilde{w}_0, \tilde{w}_1, \dots, \tilde{w}_{n-1}$ from read watermark sequence by applying,

$$\text{for example, } w_i = \begin{cases} 1 & \sum_{j=0}^{m-1} \tilde{w}_{i,j} \geq 0 \\ -1 & \sum_{j=0}^{m-1} \tilde{w}_{i,j} < 0 \end{cases}$$

- or Japanese patent application No.10-
10 219236 , "Embedding data coding method, the apparatus, computer readable medium storing embedding data coding program, read data decoding method, the apparatus, computer readable medium storing read data decoding program, digital watermark data coding
15 method, the apparatus, computer readable medium storing digital watermark coding program, digital watermark decoding method, the apparatus, computer readable medium storing digital watermark decoding program".

- 20 In addition, the above-mentioned process performed by the digital watermark reading apparatus 106 can be constructed by a program which can be stored in a computer readable medium such as a disk unit, a floppy disk, CD-ROM and the like. That is,
25 by installing the program in a computer such as one shown in Fig.17, the processes of watermark reading of the present invention can be carried out. In addition, the digital watermark reading apparatus of the present invention can be realized by the
30 integrated circuit shown in Fig.18.

Experiments is performed in order to compare the method of the present invention and the conventional method of digital watermarking to

motion pictures described in Japanese patent application No.9-164466.

As experimental conditions, a unit for digital watermark processing is assumed to be a 16
5 $\times 16$ pixel and the conventional digital watermark data sequence reading is assumed to be

$\tilde{w}_{i,j} = (n_{i,j} \bmod 2) \times 2 - 1$ on the basis of the assumptions of the above-mentioned embodiment. Watermark data is reconstituted as $\tilde{w}_0, w_1, \dots, w_{n-1}$ for both of the present
10 invention and the conventional method.

As shown in Fig.34, it is recognized that digital watermark data reading success rate is improved in an MPEG-1 coded picture in any bit rates. The result shows the effectiveness of the present
15 invention. Here, the digital watermark data reading success rate is obtained by dividing the number of correctly reconstituted digital watermark data by the total number of embedded digital watermark data.

According to the present invention, the
20 digital watermark data sequence is separated from the noise so that error bits which are included in the digital watermark data sequence can be reduced, thereby the digital watermark data reading success rate is improved in comparison with the conventional
25 method.

In addition, since weights are assigned to the digital watermark data sequence, the present invention is especially effective when the repeating number of watermark embedding is small.

The point of the present invention
30 corresponding to the third objective is applying soft decisions for the digital watermark reading process as opposed to the conventional method which uses hard decisions. The present invention is not
35 limited to the above-mentioned process and can apply

to other equivalent digital watermarking method.

In the above-mentioned embodiments corresponding to first - third objects, embodiments corresponding to each object can be performed with 5 embodiments corresponding to other objects.

The present invention is not limited to the specifically disclosed embodiments, and variations and modifications may be made without departing from the scope of the invention.

25

35

WHAT IS CLAIMED IS:

5

1. A method for embedding digital watermark data in digital data contents, said method comprising the steps of:

- 10 receiving said digital data contents and said digital watermark data;
dividing said digital data contents into block data;
obtaining a frequency coefficient of said block data;
15 obtaining a complexity of said block data;
obtaining an amount of transformation of said frequency coefficient from said complexity and said digital watermark data by using a quantization width;
20 embedding said digital watermark data in said digital data contents by transforming said frequency coefficient by said amount; and generating watermarked digital data contents.

25

2. The method as claimed in claim 1, said step of obtaining said complexity of said block data comprising the steps of:

- transforming said block data, by applying a wavelet transform, into coefficients of said wavelet transform, and
35 obtaining said complexity on the basis of the number of high frequency coefficients in said coefficients of said wavelet transform, each of said

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6. The method as claimed in claim 5, wherein said quantization width is obtained by a method comprising the steps of:

- 5 dividing first digital data contents into one or a plurality of first block data;
 dividing second digital data contents into one or a plurality of second block data, said second digital data contents being obtained by manipulating
10 said first digital data contents with a predetermined manipulation method;
 transforming said first block data and said second block data into first frequency coefficients and second frequency coefficients
15 respectively by applying an orthogonal transform;
 obtaining difference values between said first frequency coefficients and said second frequency coefficients for each frequency coefficient;
20 calculating a standard deviation of distribution of said difference values; and
 obtaining said quantization width by multiplying said standard deviation by a watermark embedding strength.

25

30 7. An apparatus for embedding digital watermark data in digital data contents, said apparatus comprising:

- means for receiving said digital data contents and said digital watermark data;
 means for dividing said digital data
35 contents into block data;
 means for obtaining a frequency coefficient of said block data;

means for obtaining a complexity of said block data;

means for obtaining an amount of transformation of said frequency coefficient from
5 said complexity and said digital watermark data by using a quantization width;

means for embedding said digital watermark data in said digital data contents by transforming said frequency coefficient by said amount; and

10 means for generating watermarked digital data contents.

15

8. The apparatus as claimed in claim 7, said means for obtaining said complexity of said block data comprising:

means for transforming said block data, by
20 applying a wavelet transform, into coefficients of said wavelet transform, and

means for obtaining said complexity on the basis of the number of high frequency coefficients in said coefficients of said wavelet transform, each
25 of said high frequency coefficients exceeding a threshold.

30

9. An apparatus for embedding digital watermark data in digital data contents, said apparatus comprising:

means for receiving said digital data
35 contents and said digital watermark data;

means for dividing said digital data contents into block data;

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means for calculating a standard deviation
of distribution of said difference values; and

means for obtaining said quantization
width by multiplying said standard deviation by a
5 watermark embedding strength.

10 11. An apparatus for reading digital
watermark data embedded in digital data contents,
said apparatus comprising:

means for receiving said digital data
contents;

15 means for dividing said digital data
contents into block data;

means for obtaining a frequency
coefficient of said block data; and

means for generating digital watermark
20 data from said frequency coefficient by using a
quantization width corresponding to said frequency
coefficient, said quantization width being obtained
beforehand according to a manipulation method of
said digital data contents.

25

12. The apparatus as claimed in claim 11,
30 wherein said quantization width is obtained by means
comprising:

means for dividing first digital data
contents into one or a plurality of first block
data;

35 means for dividing second digital data
contents into one or a plurality of second block
data, said second digital data contents being

means for generating watermarked digital data contents.

5

14. The integrated circuit as claimed in claim 13, said means for obtaining said complexity of said block data comprising:

10 means for transforming said block data, by applying a wavelet transform, into coefficients of said wavelet transform, and

means for obtaining said complexity on the basis of the number of high frequency coefficients in said coefficients of said wavelet transform, each of said high frequency coefficients exceeding a threshold.

20

15. An integrated circuit for embedding digital watermark data in digital data contents, said integrated circuit comprising:

25 means for receiving said digital data contents and said digital watermark data;

means for dividing said digital data contents into block data;

30 means for obtaining a frequency coefficient of said block data;

means for obtaining an amount of transformation of said frequency coefficient from said digital watermark data by using a quantization width corresponding to said frequency coefficient, said quantization width being obtained beforehand according to a manipulation method of said digital data contents;

coefficient;

means for calculating a standard deviation
of distribution of said difference values; and

- means for obtaining said quantization
5 width by multiplying said standard deviation by a
watermark embedding strength.

10

19. A computer readable medium storing
program code for causing a computer system to embed
digital watermark data in digital data contents,
said computer readable medium comprising:

- 15 program code means for receiving said
digital data contents and said digital watermark
data;

program code means for dividing said
digital data contents into block data;

- 20 program code means for obtaining a
frequency coefficient of said block data;

program code means for obtaining a
complexity of said block data;

- 25 program code means for obtaining an amount
of transformation of said frequency coefficient from
said complexity and said digital watermark data by
using a quantization width;

program code means for embedding said
digital watermark data in said digital data contents
30 by transforming said frequency coefficient by said
amount; and

program code means for generating
watermarked digital data contents.

35

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20. The computer readable medium as claimed in claim 19, said program code means for obtaining said complexity of said block data comprising:

15

program code means for receiving said digital data contents and said digital watermark data;

25 program code means for dividing said digital data contents into block data;

 program code means for obtaining a frequency coefficient of said block data;

 program code means for obtaining an amount of transformation of said frequency coefficient from

30 said digital watermark data by using a quantization width corresponding to said frequency coefficient, said quantization width being obtained beforehand according to a manipulation method of said digital data contents;

35 program code means for embedding said digital watermark data in said digital data contents by transforming said frequency coefficient by said

amount; and

program code means for generating
watermarked digital data contents.

5

22. The computer readable medium as
claimed in claim 21, wherein said quantization width
10 is obtained by program code means comprising:

program code means for dividing first
digital data contents into one or a plurality of
first block data;

program code means for dividing second
15 digital data contents into one or a plurality of
second block data, said second digital data contents
being obtained by manipulating said first digital
data contents with a predetermined manipulation
method;

program code means for transforming said
20 first block data and said second block data into
first frequency coefficients and second frequency
coefficients respectively by applying an orthogonal
transform;

program code means for obtaining
25 difference values between said first frequency
coefficients and said second frequency coefficients
for each frequency coefficient;

program code means for calculating a
30 standard deviation of distribution of said
difference values; and

program code means for obtaining said
quantization width by multiplying said standard
deviation by a watermark embedding strength.

35

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23. A computer readable medium storing
program code for causing a computer system to read
digital watermark data embedded in digital data
5 contents, said computer readable medium comprising:
program code means for receiving said
digital data contents;
program code means for dividing said
digital data contents into block data;
10 program code means for obtaining a
frequency coefficient of said block data; and
program code means for generating digital
watermark data from said frequency coefficient by
using a quantization width corresponding to said
15 frequency coefficient, said quantization width being
obtained beforehand according to a manipulation
method of said digital data contents.

20

24. The computer readable medium as
claimed in claim 23, wherein said quantization width
is obtained by program code means comprising:
25 program code means for dividing first
digital data contents into one or a plurality of
first block data;
program code means for dividing second
digital data contents into one or a plurality of
30 second block data, said second digital data contents
being obtained by manipulating said first digital
data contents with a predetermined manipulation
method;
program code means for transforming said
35 first block data and said second block data into
first frequency coefficients and second frequency
coefficients respectively by applying an orthogonal

transform;

15 25. A method for reading digital watermark
data embedded in digital data contents, said method
comprising the steps of:
 receiving said digital data contents;
20 reading a bit sequence from said digital
data contents;
 calculating a probability of reading a bit
'1' or a bit '0' in said bit sequence by using a
test method on the basis of binary distribution;
25 determining the presence or absence of
digital watermark data according to said
probability; and
 reconstituting and generating said digital
watermark data from said bit sequence.

26. The method as claimed in claim 25,
35 further comprising the steps of:
determining threshold α of reliability of
digital watermark data which is read;

obtaining a binary distribution function $F(x)$ which represents a probability that a number x of '1' bits or '0' bits are included in a bit sequence which is read at random from digital data contents, said binary distribution function $F(x)$ being obtained by using a probability q of reading '1' or '0' in said bit sequence and a repeating number of embedding each bit of digital watermark data;

- 10 reading an i th digital watermark sequence of said digital watermark data from a digital watermark area of said digital data contents;
 calculating the number k_i of '1' or '0' included in said digital watermark sequence;
15 calculating a probability $F(k_i)$ by using said binary distribution function $F(x)$; and
 reconstituting '1' or '0' from i th digital watermark data w_i if $F(k_i) > \alpha$, reconstituting '0' or '1' from i th digital watermark data w_i if $1-F(k_i)$
20 $> \alpha$, and determining that there is no watermark data or the presence is unknown if both of $F(k_i) > \alpha$ and $1-F(k_i) > \alpha$ are not satisfied.

25

27. The method as claimed in claim 26, further comprising the steps of:

- outputting $F(k_i)$ as reliability if said
30 reconstituted digital watermark data w_i is '1'; and
 outputting $1-F(k_i)$ as the reliability if said reconstituted digital watermark data w_i is '0'.

35

28. The method as claimed in claim 25,

further comprising the steps of:

determining a threshold α of reliability of digital watermark data which is read;

obtaining a binary distribution function
5 $F(x)$ which represents a probability that a number x
of '1' bits or '0' bits are included in a bit
sequence which is read at random from digital data
contents, said binary distribution function $F(x)$
being obtained by using a probability q of reading
10 '1' or '0' in said bit sequence and a repeating
number of embedding each bit of digital watermark
data;

reading an i th digital watermark sequence
of said digital watermark data from a digital
15 watermark area of said digital data contents;

checking whether a probability that said
digital watermark sequence is digital watermark data
exceeds said threshold α by using said binary
distribution function $F(x)$; and

20 reconstituting digital watermark data from
said digital watermark sequence by using majority
decision processing if said probability exceeds α ,
and determining that there is no watermark data or
the presence is unknown if said probability does not
25 exceed α .

30 29. The method as claimed in claim 28,
further comprising a step of outputting said
probability that said digital watermark sequence is
digital watermark data.

35

in said i th digital watermark sequence and a central value $q \times t$ of a binary distribution;

reconstituting digital watermark data by performing majority decision processing for said ith digital watermark sequence if said value is equal to or less than x_0 or equal to or more than x_i and

determining that there is no digital watermark data or the presence is unknown if said value is not equal to or less than x_0 , or equal to or more than x_1 .

15 33. The method as claimed in claim 32,
further comprising the steps of:

calculating a value of said binary
distribution function $F(z)$, z being said mean value
obtained from the number of '0' or '1' included in
20 said i th digital watermark sequence and said central
value $q \times t$; and

outputting said value of $F(z)$ as reliability of digital watermark data.

25

34. An apparatus for reading digital watermark data embedded in digital data contents, said apparatus comprising:

means for receiving said digital data contents;

means for reading a bit sequence from said digital data contents;

35 means for calculating a probability of
reading a bit '1' or a bit '0' in said bit sequence
by using a test method on the basis of binary

distribution;

means for determining the presence or absence of digital watermark data according to said probability; and

- 5 means for reconstituting said digital watermark data from said bit sequence.

10

35. The apparatus as claimed in claim 34, further comprising:

- means for obtaining a binary distribution function $F(x)$ which represents a probability that a
15 number x of '1' bits or '0' bits are included in a bit sequence which is read at random from digital data contents, said binary distribution function $F(x)$ being obtained by using a probability q of reading '1' or '0' in said bit sequence and a
20 repeating number of embedding each bit of digital watermark data;

- means for reading an i th digital watermark sequence of said digital watermark data from a digital watermark area of said digital data
25 contents;

means for calculating the number k_i of '1' or '0' included in said digital watermark sequence;

means for calculating a probability $F(k_i)$ by using said binary distribution function $F(x)$; and

- 30 means for reconstituting '1' or '0' from i th digital watermark data w_i if $F(k_i) > \alpha$, reconstituting '0' or '1' from i th digital watermark data w_i if $1-F(k_i) > \alpha$, and, determining that there is no watermark data or the presence is unknown if
35 both of $F(k_i) > \alpha$ and $1-F(k_i) > \alpha$ are not satisfied, α being a threshold of reliability of digital watermark data which is read.

5 36. The apparatus as claimed in claim 35,
further comprising:

means for outputting $F(k_i)$ as reliability
if said reconstituted digital watermark data w_i is
'1'; and

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10         means for outputting 1-F(ki) as
        reliability if said reconstituted digital watermark
        data wi is '0'.

```

15

37. The apparatus as claimed in claim 34,
further comprising:

means for obtaining a binary distribution
20 function $F(x)$ which represents a probability that a
number x of '1' bits or '0' bits are included in a
bit sequence which is read at random from digital
data contents, said binary distribution function
 $F(x)$ being obtained by using a probability q of
25 reading '1' or '0' in said bit sequence and a
repeating number of embedding each bit of digital
watermark data;

means for reading an *i*th digital watermark
sequence of said digital watermark data from a
30 digital watermark area of said digital data
contents;

means for checking whether a probability that said digital watermark sequence is digital watermark data exceeds said threshold α by using 35 said binary distribution function $F(x)$, α being a threshold of reliability of digital watermark data which is read; and

35

means for reconstituting and generating digital watermark data from said digital watermark sequence by using majority decision processing if said probability exceeds α , and, determining that
5 there is no watermark data or the presence is unknown if said probability does not exceed α .

10

38. The apparatus as claimed in claim 37, further comprising means for outputting said probability that said digital watermark sequence is digital watermark data.

15

39. The apparatus as claimed in claim 34,
20 if a data sequence which is embedded as said digital watermark data is modulated by a pseudo-random sequence, said apparatus further comprising:
means for demodulating said bit sequence
by said pseudo-random sequence; and
25 means for reconstituting digital watermark data from said demodulated bit sequence.

30

40. The apparatus as claimed in claim 34,
if a data sequence which is embedded as said digital watermark data is modulated by a pseudo-random sequence, said apparatus further comprising:
35 means for obtaining a binary distribution function $F(x)$ which represents a probability that a number x of '1' bits or '0' bits are included in a

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bit sequence which is read at random from digital data contents, said binary distribution function $F(x)$ being obtained by using a probability q of reading '1' or '0' in said bit sequence and a

- 5 repeating number t of embedding each bit of digital watermark data;

means for reading an i th digital watermark sequence of said digital watermark data from a digital watermark area of said digital data

- 10 contents;

means for demodulating said digital watermark sequence by said pseudo-random sequence;

means for assigning $1/2$ to said probability q ;

- 15 means for obtaining x_0 or x_1 which satisfies $0 \leq F(x=x_0) \leq 1-\alpha$ or $\alpha \leq F(x=x_1) \leq 1$, α being a threshold of reliability of digital watermark data which is read;

- means for determining whether a value is
20 equal to or less than x_0 or equal to or more than x_1 , said value being a mean value of absolute values of a difference between the number of '0' or '1' included in said i th digital watermark sequence and a central value $q \times t$ of a binary distribution;

- 25 means for reconstituting digital watermark data by performing majority decision processing for said i th digital watermark sequence if said value is equal to or less than x_0 or equal to or more than x_1 ; and

- 30 means for determining that there is no digital watermark data or the presence is unknown if said value is not equal to or less than x_0 or equal to or more than x_1 .

number x of '1' bits or '0' bits are included in a bit sequence which is read at random from digital data contents, said binary distribution function $F(x)$ being obtained by using a probability q of
5 reading '1' or '0' in said bit sequence and a repeating number of embedding each bit of digital watermark data;

means for reading an i th digital watermark sequence of said digital watermark data from a
10 digital watermark area of said digital data contents;

means for calculating the number k_i of '1' or '0' included in said digital watermark sequence;

means for calculating a probability $F(k_i)$
15 by using said binary distribution function $F(x)$; and
means for reconstituting '1' or '0' from i th digital watermark data w_i if $F(k_i) > \alpha$, reconstituting '0' or '1' from i th digital watermark data w_i if $1-F(k_i) > \alpha$, and determining that there
20 is no watermark data or the presence is unknown if both of $F(k_i) > \alpha$ and $1-F(k_i) > \alpha$ are not satisfied, α being a threshold of reliability of digital watermark data which is read.

25

45. The integrated circuit as claimed in claim 44, further comprising:

30 means for outputting $F(k_i)$ as reliability if said reconstituted digital watermark data w_i is '1'; and

means for outputting $1-F(k_i)$ as reliability if said reconstituted digital watermark
35 data w_i is '0'.

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46. The integrated circuit as claimed in claim 43, further comprising:

- 5 means for obtaining a binary distribution function $F(x)$ which represents a probability that a number of x of '1' bits or '0' bits are included in a bit sequence which is read at random from digital data contents, said binary distribution function
- 10 $F(x)$ being obtained by using a probability q of reading '1' or '0' in said bit sequence and a repeating number of embedding each bit of digital watermark data;
- 15 means for reading an i th digital watermark sequence of said digital watermark data from a digital watermark area of said digital data contents;
- 20 means for checking whether a probability that said digital watermark sequence is digital watermark data exceeds said threshold α by using said binary distribution function $F(x)$, α being a threshold of reliability of digital watermark data which is read; and
- 25 means for reconstituting and generating digital watermark data from said digital watermark sequence by using majority decision processing if said probability exceeds α , and, determining that there is no watermark data or the presence is unknown if said probability does not exceed α .

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- 35 47. The integrated circuit as claimed in claim 46, further comprising means for outputting said probability that said digital watermark sequence is digital watermark data.

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watermark sequence by said pseudo-random sequence;
means for assigning $1/2$ to said
probability α ;

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means for calculating a value of said
30 binary distribution function $F(z)$, z being said mean
value obtained from the number of '0' or '1'
included in said i th digital watermark sequence and
said central value $\alpha \times t$; and

52. A computer readable medium storing
program code for causing a computer system to read
5 digital watermark data embedded in digital data
contents, said computer readable medium comprising:
program code means for receiving said
digital data contents;
program code means for reading a bit
10 sequence from said digital data contents;
program code means for calculating a
probability of reading a bit '1' or a bit '0' in
said bit sequence by using a test method on the
basis of binary distribution;
15 program code means for determining the
presence or absence of digital watermark data
according to said probability; and
program code means for reconstituting and
generating said digital watermark data from said bit
20 sequence.

53. The computer readable medium as
25 claimed in claim 52, further comprising:
program code means for obtaining a binary
distribution function $F(x)$ which represents a
probability that a number x of '1' bits or '0' bits
30 are included in a bit sequence which is read at
random from digital data contents, said binary
distribution function $F(x)$ being obtained by using a
probability q of reading '1' or '0' in said bit
sequence and a repeating number of embedding each
35 bit of digital watermark data;
program code means for reading an i th
digital watermark sequence of said digital watermark

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data from a digital watermark area of said digital data contents;

program code means for calculating the number k_i of '1' or '0' included in said digital watermark sequence; and

program code means for calculating a probability $F(k_i)$ by using said binary distribution function $F(x)$;

program code means for reconstituting '1' or '0' from i th digital watermark data w_i if $F(k_i) > \alpha$, reconstituting '0' or '1' from i th digital watermark data w_i if $1-F(k_i) > \alpha$, and, determining that there is no watermark data or the presence is unknown if both of $F(k_i) > \alpha$ and $1-F(k_i) > \alpha$ are not satisfied, α being a threshold of reliability of digital watermark data which is read.

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54. The computer readable medium as claimed in claim 53, further comprising:

program code means for outputting $F(k_i)$ as reliability if said reconstituted digital watermark data w_i is '1'; and

program code means for outputting $1-F(k_i)$ as reliability if said reconstituted digital watermark data w_i is '0'.

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55. The computer readable medium as claimed in claim 52, further comprising:

program code means for obtaining a binary distribution function $F(x)$ which represents a probability that a number x of '1' bits or '0' bits

are included in a bit sequence which is read at random from digital data contents, said binary distribution function $F(x)$ being obtained by using a probability q of reading '1' or '0' in said bit sequence and a repeating number of embedding each bit of digital watermark data;

program code means for reading an i th digital watermark sequence of said digital watermark data from a digital watermark area of said digital data contents;

program code means for checking whether a probability that said digital watermark sequence is digital watermark data exceeds said threshold α by using said binary distribution function $F(x)$, α being a threshold of reliability of digital watermark data which is read; and

program code means for reconstituting and generating digital watermark data from said digital watermark sequence by using majority decision processing if said probability exceeds α , and determining that there is no watermark data or the presence is unknown if said probability does not exceed α .

25

56. The computer readable medium as claimed in claim 55, further comprising program code means for outputting said probability that said digital watermark sequence is digital watermark data as reliability of said reconstituted digital watermark data.

35

program code means for assigning $1/2$ to said probability q ;

program code means for obtaining x_0 or x_1 which satisfies $0 \leq F(x=x_0) \leq 1-\alpha$ or $\alpha \leq F(x=x_1) \leq 1$, α being a threshold of reliability of digital watermark data which is read;

program code means for determining whether a value is equal to or less than x_0 or equal to or more than x_1 , said value being a mean value of absolute values of a difference between the number of '0' or '1' included in said i th digital watermark sequence and a central value $q \times t$ of a binary distribution;

program code means for reconstituting digital watermark data by performing majority decision processing for said i th digital watermark sequence if said value is equal to or less than x_0 or equal to or more than x_1 ; and

program code means for determining that there is no digital watermark data or the presence is unknown if said value is not equal to or less than x_0 or equal to or more than x_1 .

25

60. The computer readable medium as claimed in claim 59, further comprising:

program code means for calculating a value of said binary distribution function $F(z)$, z being said mean value obtained from the number of '0' or '1' included in said i th digital watermark sequence and said central value $q \times t$; and

program code means for outputting said value of $F(z)$ as reliability of digital watermark data.

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64. An apparatus for reading digital watermark data from digital data contents in which each bit of digital watermark data is embedded a plurality of times, said apparatus comprising:

- means for receiving digital data contents;
- means for reading a digital watermark sequence from said digital data contents;
- means for performing soft decision in code theory by assigning weights to said digital watermark sequence with a weighting function; and
- means for reconstituting and generating digital watermark data from said digital watermark sequence.

15

65. The apparatus as claimed in claim 64,

wherein said weighting function is a distribution function obtained by means comprising:

- means for dividing first digital data contents into one or a plurality of first block data;
- means for dividing second digital data contents into one or a plurality of second block data, said second digital data contents being obtained by manipulating said first digital data contents with a predetermined manipulation method;
- means for transforming said first block data and said second block data into first frequency coefficients and second frequency coefficients respectively by applying an orthogonal transform; and
- means for obtaining a distribution of difference values between said first frequency coefficients and said second frequency coefficients,

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said distribution function being an approximation of said distribution,

wherein said weights are assigned to said digital watermark sequence according to values of
5 said distribution function.

10 66. The apparatus as claimed in claim 64,
wherein said weighting function is a distribution function obtained by means comprising:
means for dividing first digital data
contents into one or a plurality of first block
15 data;
means for dividing second digital data
contents into one or a plurality of second block data, said second digital data contents being
obtained by manipulating said first digital data
20 contents with a predetermined manipulation method;
means for transforming said first block data and said second block data into first frequency
coefficients and second frequency coefficients
respectively by applying an orthogonal transform ;
25 means for obtaining said distribution
function on the basis of a theory if a distribution of difference values between said first frequency
coefficients and said second frequency coefficients
can be obtained by said theory, and
30 wherein said weights are assigned to said
digital watermark sequence according to values of
said distribution function.

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67. An integrated circuit for reading

said distribution,

wherein said weights are assigned to said digital watermark sequence according to values of said distribution function.

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69. The integrated circuit as claimed in claim 67, wherein said weighting function is a distribution function obtained by means comprising:

means for dividing first digital data contents into one or a plurality of first block data;

means for dividing second digital data contents into one or a plurality of second block data, said second digital data contents being obtained by manipulating said first digital data contents with a predetermined manipulation method;

means for transforming said first block data and said second block data into first frequency coefficients and second frequency coefficients respectively by applying an orthogonal transform; and

means for obtaining said distribution function on the basis of a theory if a distribution of difference values between said first frequency coefficients and said second frequency coefficients can be obtained by said theory,

wherein said weights are assigned to said digital watermark sequence according to values of said distribution function.

35

70. A computer readable medium storing

program code for causing a computer system to read digital watermark data from digital data contents in which each bit of digital watermark data is embedded a plurality of times, said computer readable medium comprising:

program code means for receiving digital data contents;

program code means for reading a digital watermark sequence from said digital data contents;

program code means for performing soft decision in code theory by assigning weights to said digital watermark sequence with a weighting function; and

program code means for reconstituting and generating digital watermark data from said digital watermark sequence.

71. The computer readable medium as claimed in claim 70, wherein said weighting function is a distribution function obtained by program code means comprising:

program code means for dividing first digital data contents into one or a plurality of first block data;

program code means for dividing second digital data contents into one or a plurality of second block data, said second digital data contents being obtained by manipulating said first digital data contents with a predetermined manipulation method;

program code means for transforming said first block data and said second block data into first frequency coefficients and second frequency coefficients respectively by applying an orthogonal

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digital watermark sequence according to values of
said distribution function.

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ABSTRACT OF THE DISCLOSURE

A method for embedding digital watermark data in digital data contents includes the steps of obtaining a frequency coefficient of block data of digital data contents, obtaining a complexity of the block data, obtaining an amount of transformation of the frequency coefficient from the complexity and the digital watermark data, and embedding the digital watermark data by transforming the frequency coefficient. In addition, a method for reading digital watermark data includes the steps of calculating a probability of reading '1' or '0' in a read bit sequence by using a test method on the basis of binary distribution, determining the presence or absence of digital watermark data according to the probability, and reconstituting digital watermark data. Another method includes the steps of performing soft decision in code theory by assigning weights to the digital watermark sequence with a weighting function, and reconstituting digital watermark data.

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FIG. 1

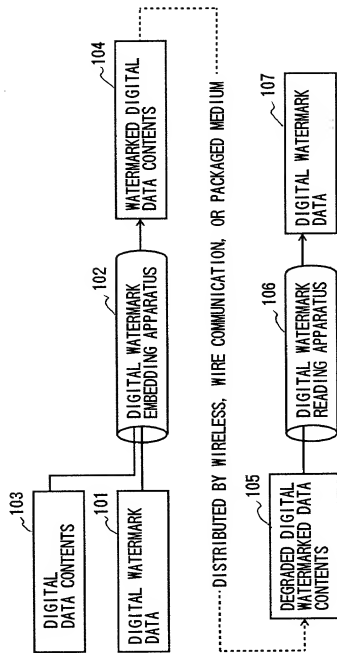


FIG.3 PRIOR ART

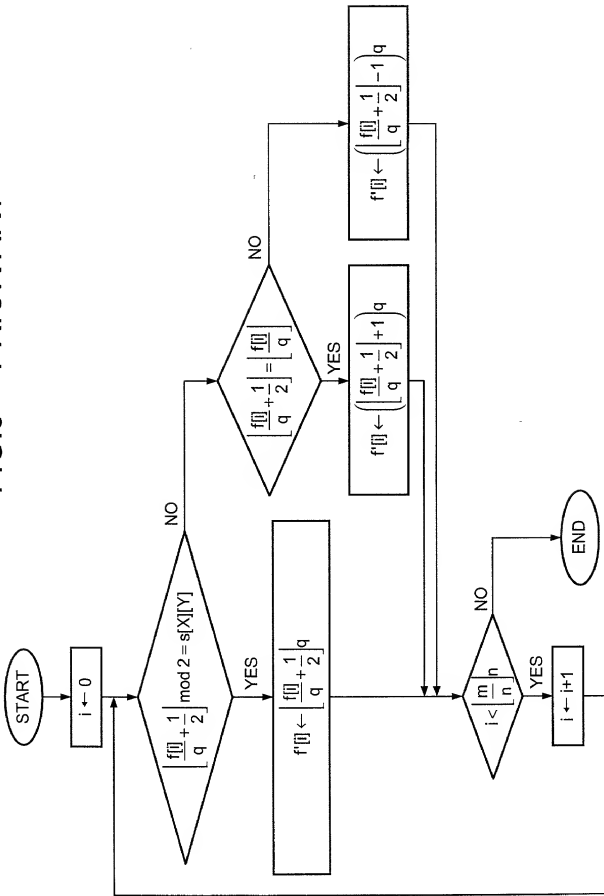


FIG. 4 PRIOR ART

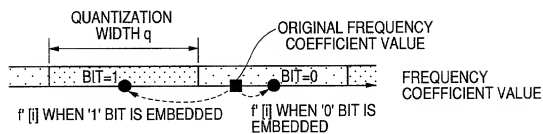


FIG.5 PRIOR ART

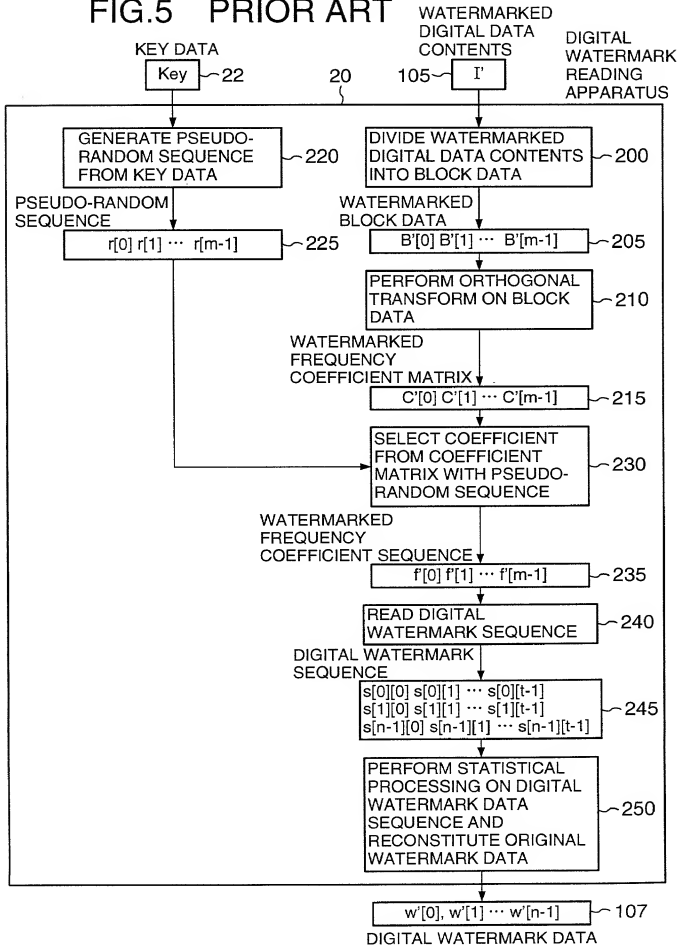


FIG.6 PRIOR ART

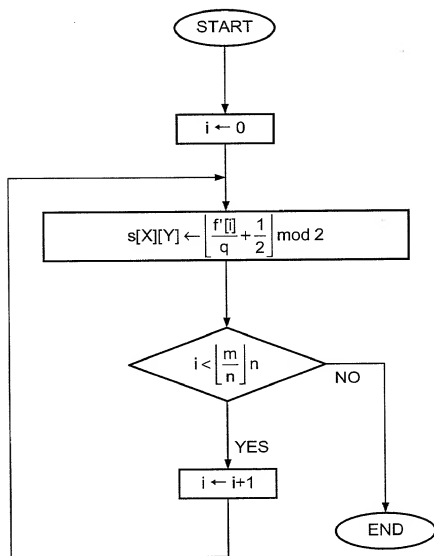


FIG.7

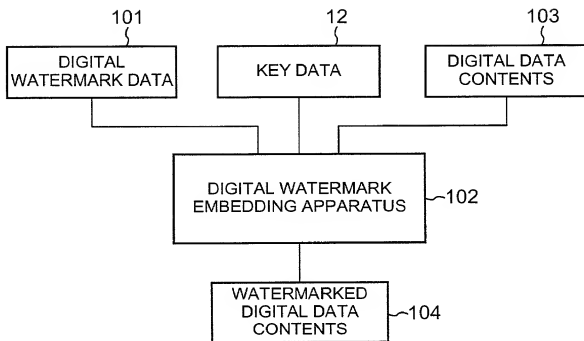


FIG.8

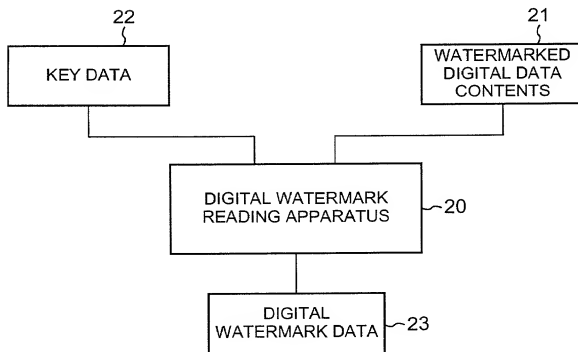
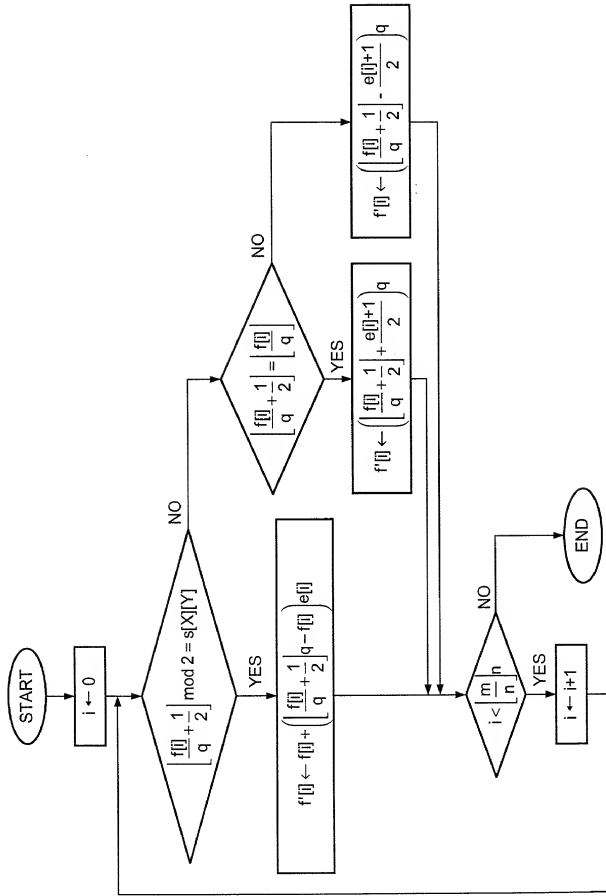


FIG.10



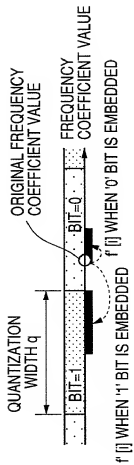


FIG. 11A

ENLARGED FIGURE

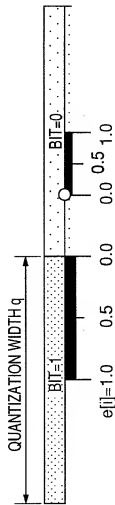
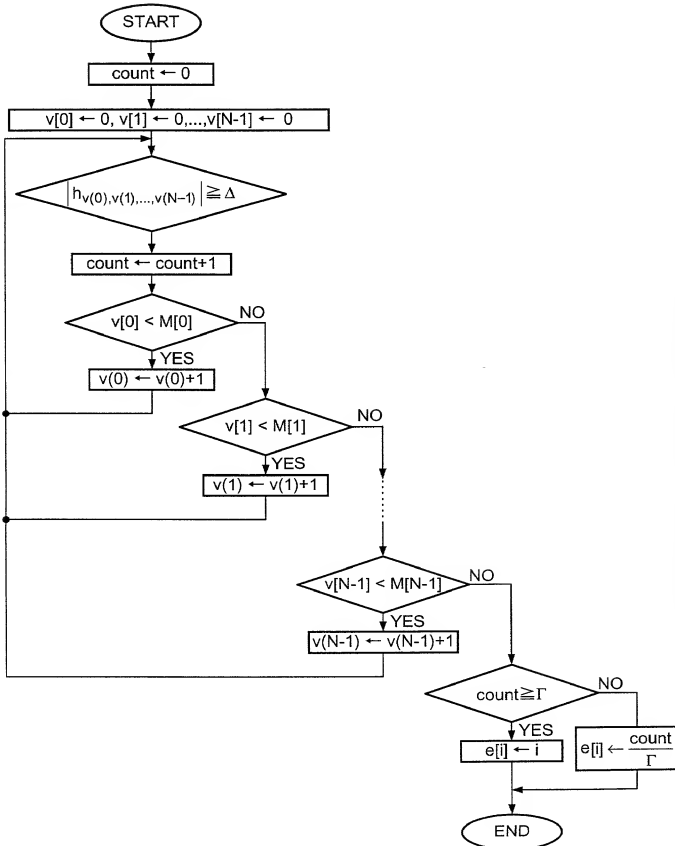


FIG. 11B

FIG.12



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FIG.13

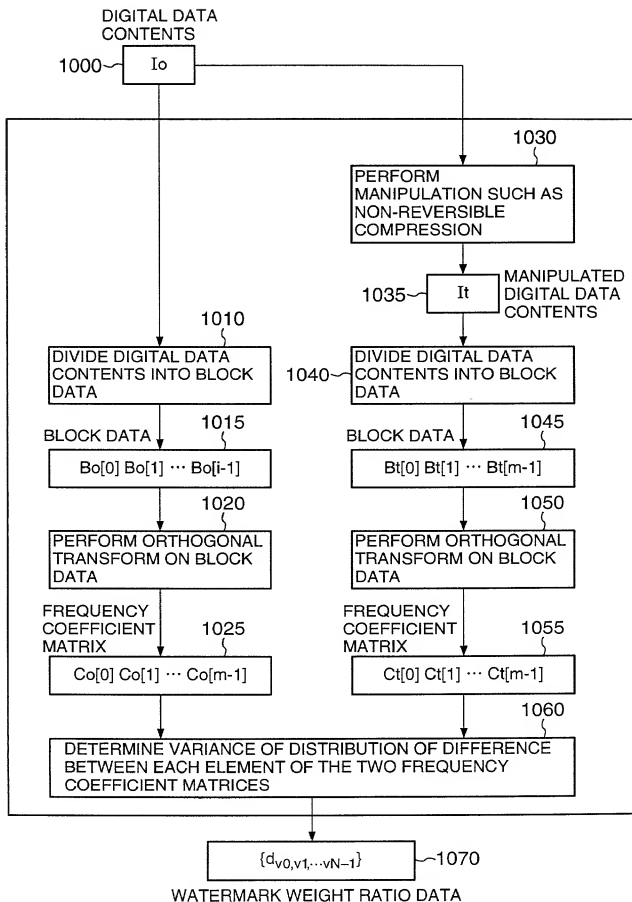


FIG.14

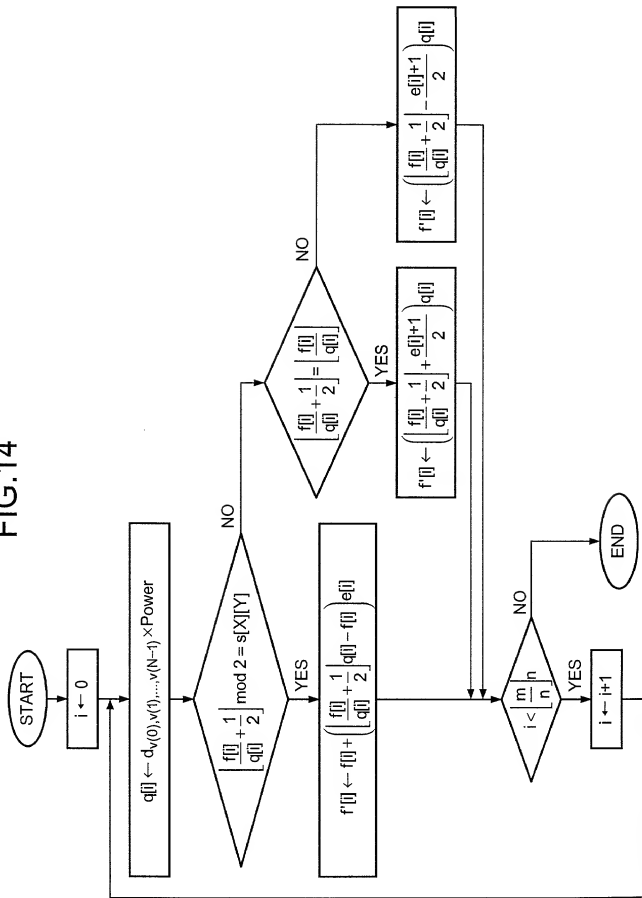


FIG.15

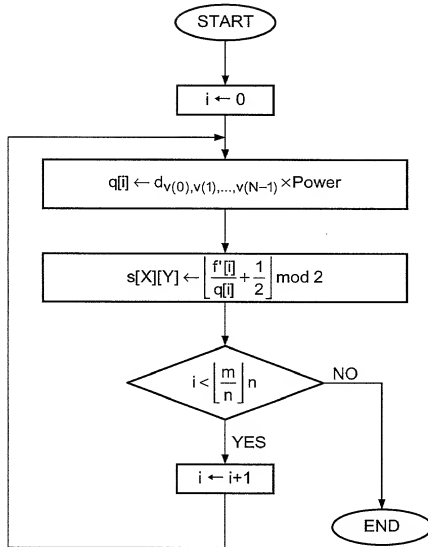


FIG.16

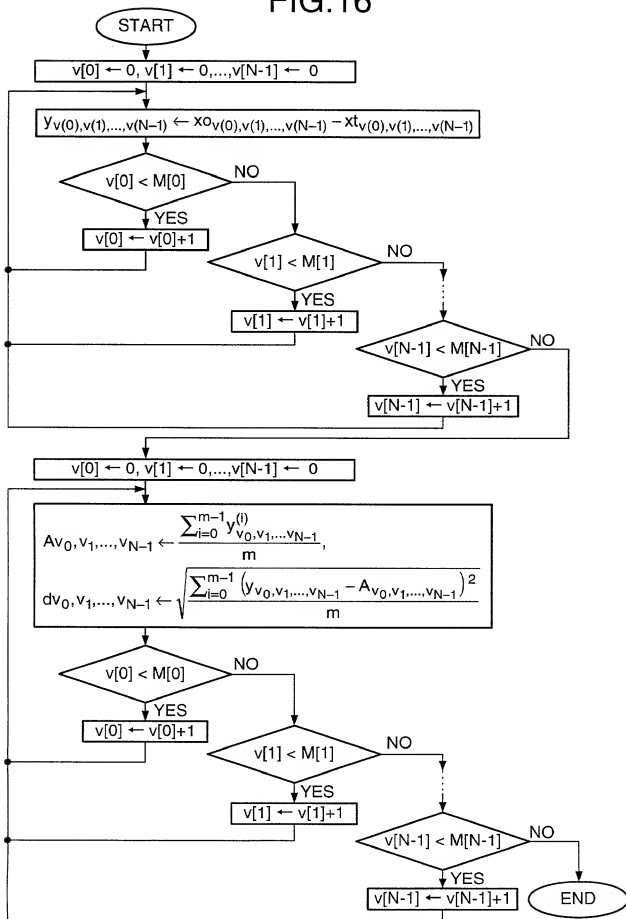


FIG.17

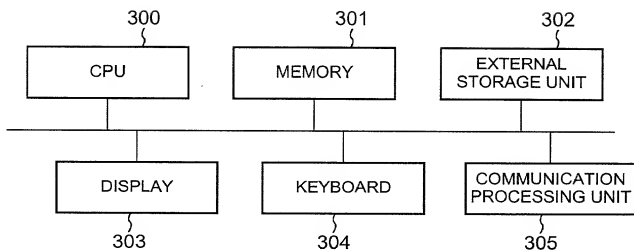


FIG.18

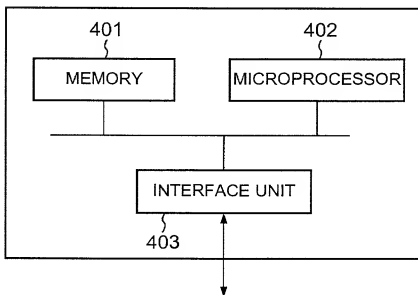


FIG. 19

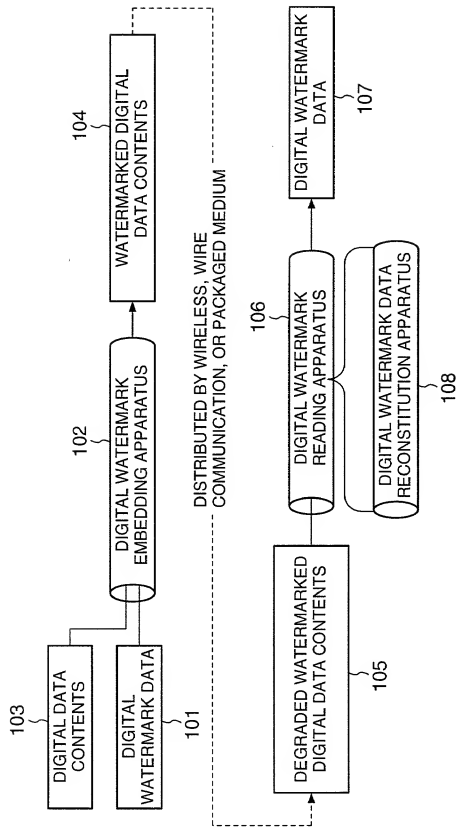


FIG.20

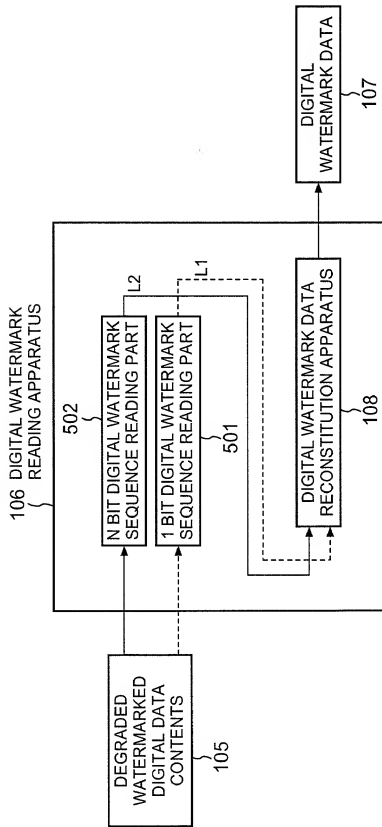


FIG.21

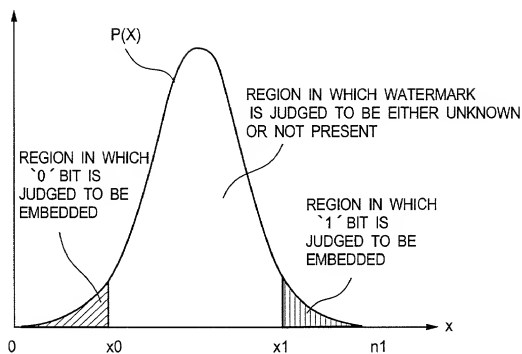
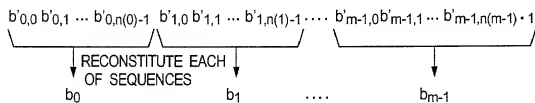


FIG.22



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FIG. 24

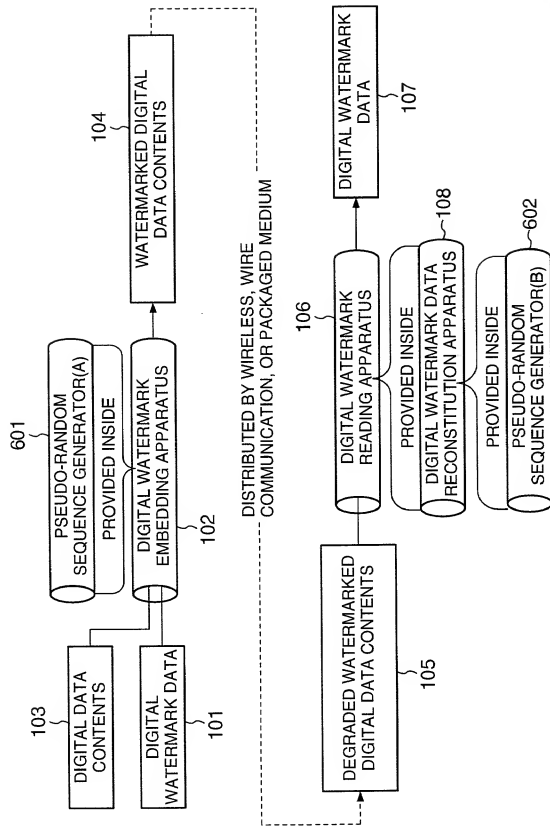


FIG.25

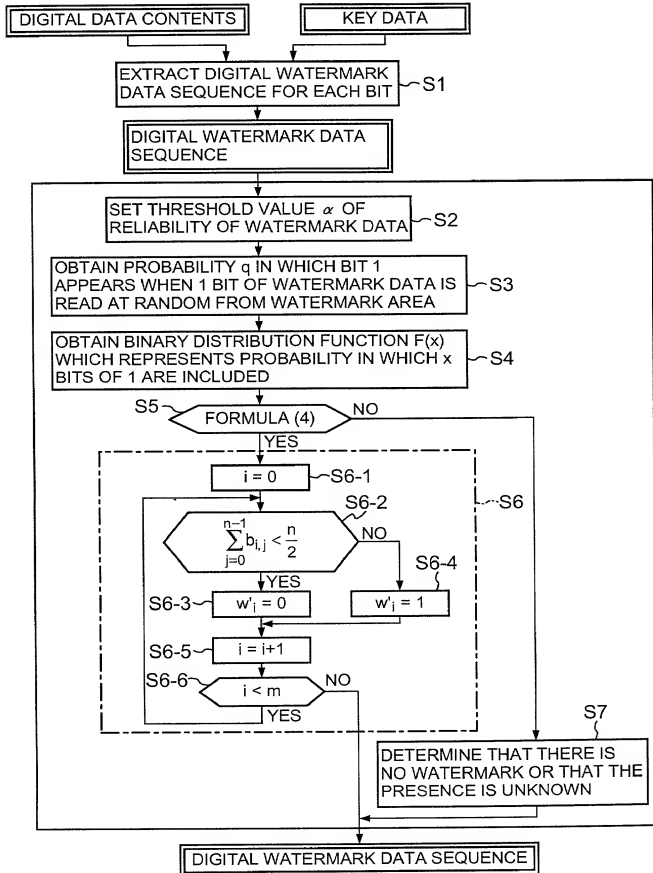


FIG.26

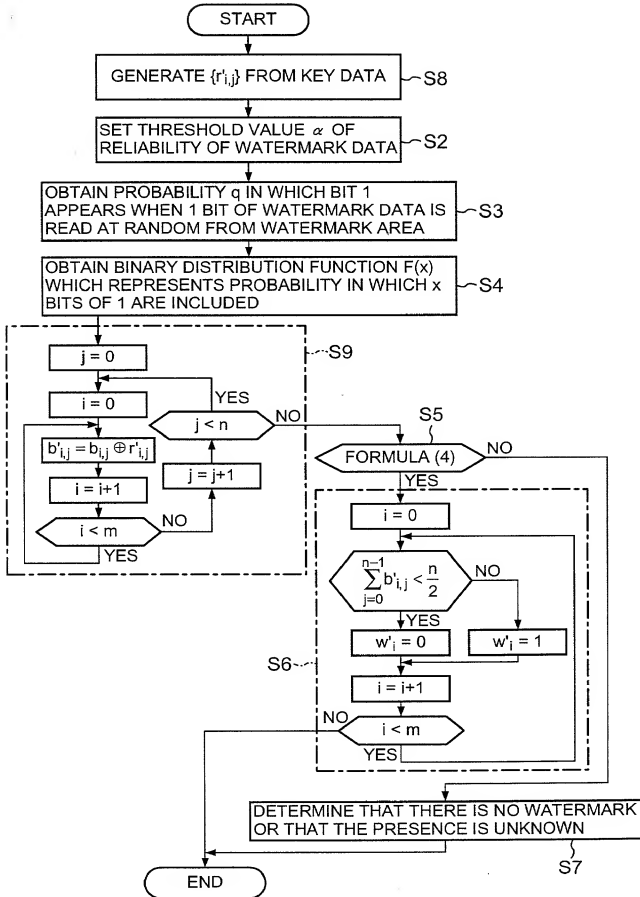


FIG.27

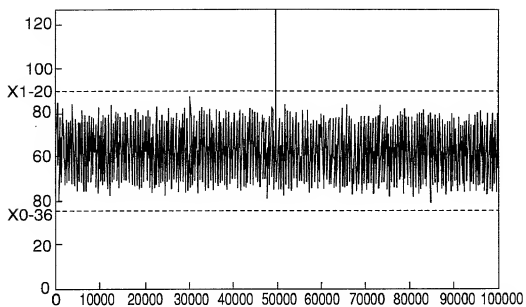


FIG.28

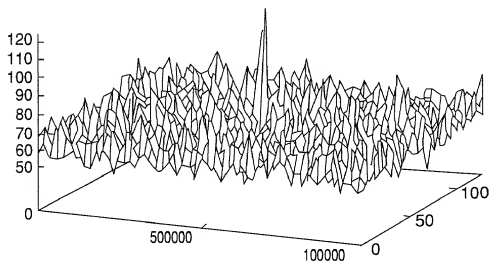
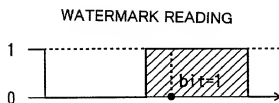
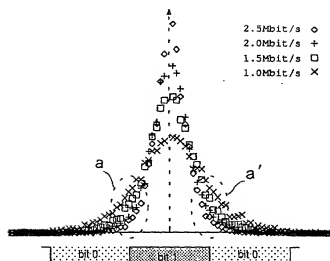


FIG. 29 PRIOR ART



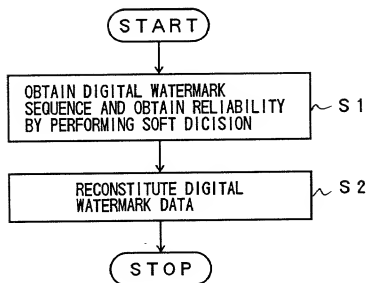
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FIG.30



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FIG. 31



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FIG. 33

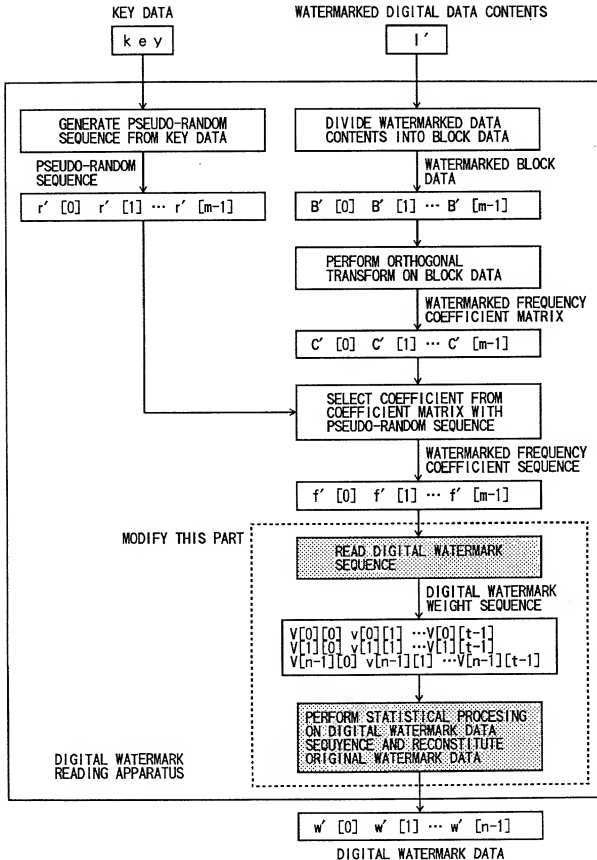
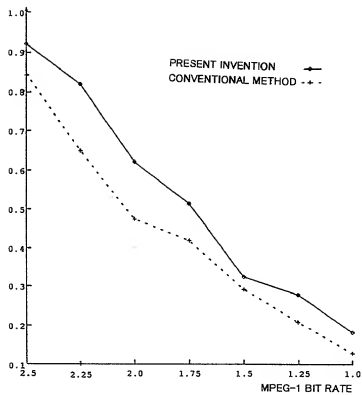


FIG.34



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DECLARATION AND POWER OF ATTORNEY - ORIGINAL APPLICATION

ATTORNEY'S DOCKET NO.

10746/11

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled
METHOD AND APPARATUS FOR DIGITAL WATERMARKING

the specification of which

(check one)

☒ is attached hereto.

☐ was filed on _____ as Application Serial No. _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

COUNTRY	APPLICATION NUMBER	DATE OF FILING (day, month, year)	DATE OF ISSUE (day, month, year)	PRIORITY CLAIMED UNDER 35 USC 119
as per attached				<input type="checkbox"/> YES <input type="checkbox"/> NO
				<input type="checkbox"/> YES <input type="checkbox"/> NO

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION NO.	FILING DATE (day, month, year)	STATUS (i.e. Patented, Pending, Abandoned)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute the application and transact all business in the Patent and Trademark Office connected therewith. (List name and registration number)

Edward W. Greason, Esq.
Reg. No. 18,918

SEND CORRESPONDENCE TO:

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One Broadway
New York, New York 10004

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	POST OFFICE ADDRESS	POST OFFICE ADDRESS as per attached	CITY as per attached	STATE & ZIP CODE/COUNTRY Japan
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	POST OFFICE ADDRESS	POST OFFICE ADDRESS as per attached	CITY as per attached	STATE & ZIP CODE/COUNTRY Japan
205	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE OR FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY
206	FULL NAME OF INVENTOR	FAMILY NAME	FIRST GIVEN NAME	SECOND GIVEN NAME
	RESIDENCE & CITIZENSHIP	CITY	STATE OR FOREIGN COUNTRY	COUNTRY OF CITIZENSHIP
	POST OFFICE ADDRESS	POST OFFICE ADDRESS	CITY	STATE & ZIP CODE/COUNTRY
<p>I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.</p>				
SIGNATURE OF INVENTOR 201		SIGNATURE OF INVENTOR 202		SIGNATURE OF INVENTOR 203
<i>Hiroshi Ogawa</i>		<i>Nakamura Takao</i>		<i>Atsuki Tomioaka</i>
DATE August 26, 1999		DATE August 26, 1999		DATE August 26, 1999
SIGNATURE OF INVENTOR 204		SIGNATURE OF INVENTOR 205		SIGNATURE OF INVENTOR 206
<i>Yuuichi Takashima</i>				
DATE August 26, 1999		DATE		DATE

ATTACHMENT TO DECLARATION AND POWER OF ATTORNEY

PRIOR FOREIGN APPLICATIONS AS FOLLOWS:

<u>COUNTRY</u>	<u>APPLICATION NUMBER</u>	<u>DATE OF FILING</u> (Day/Month/Year)	<u>PRIORITY CLAIMED</u>
----------------	---------------------------	---	-------------------------

Japan	Patent Application No.10-251193	04/09/98	YES
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Japan	Patent Application No.11-30540	08/02/99	YES
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Japan	Patent Application No.11-40713	18/02/99	YES
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Japan	Patent Application No.11-118072	26/04/99	YES
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